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FOREWORD

This special publication documents presentations at a special session on national arctic research programs. This special session was organized by the Polar Technology Working Group, an informal body of individuals from the United States, Canada, Finland, Denmark, Norway and Sweden. The authors of the presentations informally represented their government-related activities. Government programs on polar technology (of the Arctic and Antarctic) appear to be scattered throughout many agencies in many countries. Interactions at an international level among the governments on the technology issues are slowly evolving. This session brought major parties together in exchange of government (and some industry) research activities, policies and expenditure allocations. It is hoped that this first session will open a door for international consultation and cooperation in effective technology transfer in the future, as well as informing the general public and industry on arctic and antarctic research activities. There are many opportunities for coordinated research among these nations to significantly extend the return on investment received for the resources applied in this area. It is hoped that such presentations will continue in the future.

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GOVERNMENT-SPONSORED ARCTIC RESEARCH IN CANADA

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Much of Canada is characterized by arctic conditions. With almost 4 million square kilometres (about 40% of the total land area) lying north of latitude 60°N, Canada has more arctic territory than any other nation except the Soviet Union. To appreciate the northern interests of Canada one must also include the large offshore areas under Canadian jurisdiction (Fig. 1). With responsibility for such vast areas, the Government of Canada clearly has a keen interest in arctic research.

This paper deals with research sponsored by the federal government, focuses on the natural sciences and engineering, and stresses the offshore aspects. It does not cover the social sciences.

This paper presents an overview of [illegible] key government departments and agencies involved in arc[illegible] research; refers to several special R&D programs introduced to address, at least in part, arctic problems; comments on some specific R&D activities; and presents two current policy issues that will influence Canadian arctic science.

THE CANADIAN ARCTIC

For the purpose of this paper, the Arctic is defined as the area north of the boundary of discontinuous permafrost (see Fig. 1). In western Canada, this boundary lies at about

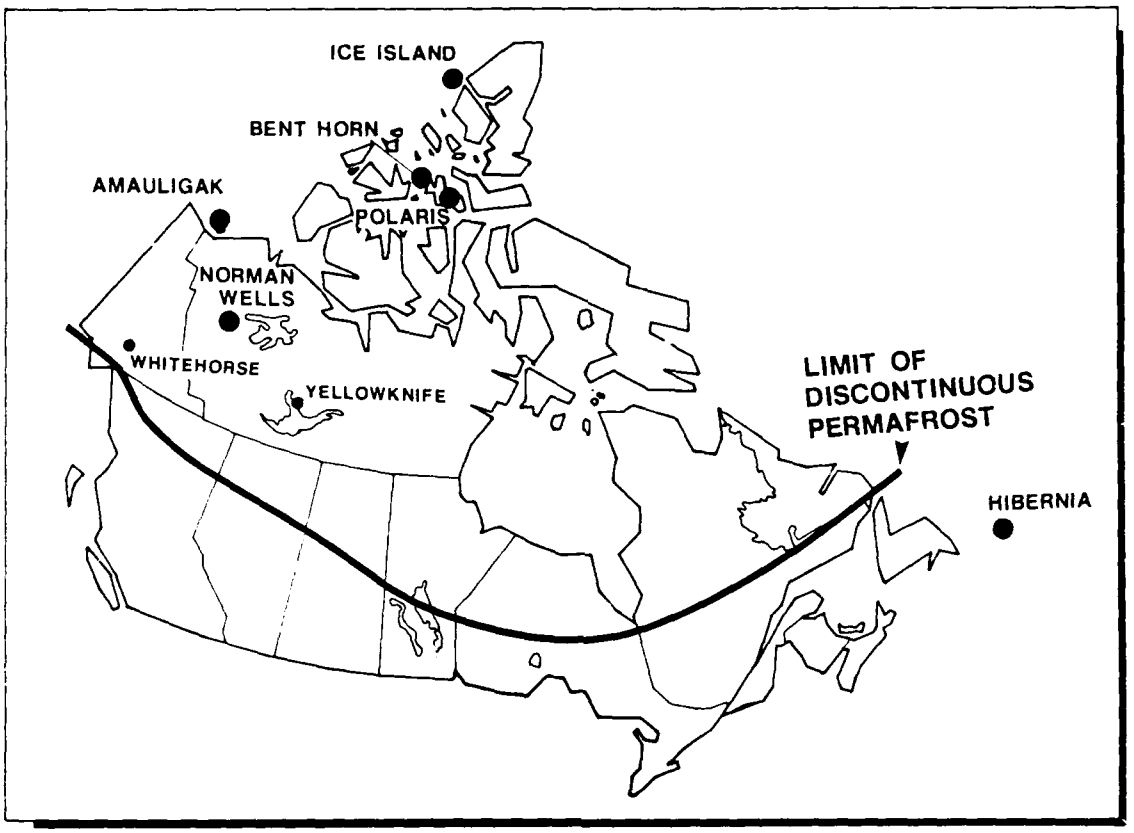

Figure 1. Location map.

latitude 60°N, but east of Hudson Bay it reaches south to about latitude 52°N. Arctic conditions extend far to the south in eastern Canada, both onshore and offshore. Sea ice interrupts offshore drilling operations at the Hibernia oilfield every winter and icebergs harass activities for about six months every year; yet, the site is only at latitude 48°N.

Although arctic Canada is extensive, its population is only about 75 000 persons, of which about one-third lives in the two territorial capitals; two-thirds are in scattered smaller settlements. Traditional hunting and trapping are still important, but the key revenue-producing industries are oil and gas and mining. Production at the Norman Wells oil field was recently expanded and oil is now shipped south via pipeline. Seasonal production has started from the Bent Horn oil field in the Arctic Archipelago and the Amauligak field in the Beaufort Sea is being developed. This latter development is expected to

be the first of several in that area. Ore is produced at several mines, including the Polaris mine. Located at about latitude 75°N, Polaris is the northernmost mine site in the world. The Bent Horn oil field and the Polaris mine rely on ice-strengthened ships for transportation of supplies and products.

South of latitude 60°N, Canada is divided into provinces and some provincial governments foster cold-region R&D activities to address problems in their northern areas. North of latitude 60°N, in the Northwest and Yukon territories, federal agencies dominate the R&D activities, although the territorial governments support wildlife studies. The offshore areas remain under federal jurisdiction. The federal government also has responsibility for native people and for the management of resources, such as water and air, that transcend provincial boundaries.

GOVERNMENT-SPONSORED RESEARCH

The Government of Canada sponsors arctic research in a variety of ways, and the research activities can be broadly divided in two categories: first, government-based R&D where the government agencies develop, perform, and/or directly manage the R&D activities and, secondly, private sector-based R&D in which the government is essentially a funding agency whereas the science projects themselves are conceived and carried out within the private sector. University-based R&D is included here.

Government-based R&D

The need to ensure effective implementation of government programs and services, including the maintenance of sovereignty, is a primary reason for funding arctic research. Initially, research focused on descriptions and regional surveys of arctic resources and phenomena during what could be described as the exploratory phase of northern R&D. However, as plans were developed for exploitation of the resources on a

major scale, the research became increasingly problem-oriented and government departments focused more and more on regulatory and resource management issues. During the last two decades, a major part of government research has related to environmental assessments of large energy development projects.

Basic, curiosity-driven research, motivated only by the desire to understand the Arctic and cold-climate processes have been a key part of northern research. But several scientists have expressed deep concern that this type of activity has suffered in recent years from the heavy demands for short-term solutions.

Of several government departments involved in arctic research, the Department of Indian and Northern Affairs has a unique mandate to "support and foster Arctic research." This department supports the Northern Scientific Training Program and operates three northern scientific research stations (in Inuvik, Igloolik, and Iqaluit). The research stations will, however, be transferred to the Science Institute of the Northwest Territories on the 1 October 1988 to promote greater participation by northeners in science and technology programs.

Besides supporting and fostering, key departments involved in conducting arctic research are the departments of Energy, Mines and Resources, of Fisheries and Oceans, of the Environment, and the National Research Council of Canada. These have scientific staff and facilities, including ships, to support in-house scientific activities as well as managing R&D programs contracted to the private sector. The principal arctic-oriented units of government departments are listed in Table 1. All centres are national in character and, with one exception, are not specifically dedicated to arctic research. Other departments, for example the Department of Transport, provide extensive extramural funding for R&D to support their missions. The Department of National Defence also supports arctic research, mainly through in-house and classified projects.

TABLE 1

Federal Department and Agency
Centres With Arctic R&D Expertise

Department/Agency	Location
ENERGY, MINES AND RESOURCES	
o Geological Survey of Canada (GSC)	Ottawa, Ont.
. Atlantic Geoscience Centre	Bedford Institute of Oceanography Dartmouth, N.S.
. Pacific Geoscience Centre	Institute of Ocean Sciences Sidney, B.C.
. Institute of Sedimentary Petroleum Geology	Calgary, Alta.
o Canada Centre for Mineral and Energy Technology (CANMET)	Ottawa, Ont.
o Polar Continental Shelf Project (PCSP) (logistics)	Ottawa, Ont. Tuk, Resolute Bay
o Canada Centre for Remote Sensing (CCRS)	Ottawa, Ont.
. Radarsat Project Office	Ottawa, Ont.
FISHERIES AND OCEANS	
o Oceanographic Sciences	Ottawa, Ont.
. Bedford Institute of Oceanography	Dartmouth, N.S.
. Institute of Ocean Sciences	Sidney, B.C.
. Marine Environmental Data Services	Ottawa, Ont.

Table 1 (continued)

Department/Agency	Location
FISHERIES AND OCEANS (cont'd)	
o Fisheries and Biological Sciences	
. Arctic Biological Station	St. Anne de Bellevue, Que.
. Freshwater Institute	Winnipeg, Man.
o Canadian Hydrographic Service (under-ice surveys)	Ottawa and Regional Offices
ENVIRONMENT CANADA	
o Atmospheric Environment Service	Downsview, Ont.
. Ice Centre	Ottawa, Ont.
. Atmospheric Processes Research	Downsview, Ont.
. Climate Research	Downsview, Ont.
o Conservation and Protection	Ottawa, Ont.
. Environment Technology Centre	Ottawa, Ont.
. Canadian Wildlife Service	Ottawa, Ont. and Regional Offices
NATIONAL RESEARCH COUNCIL	Ottawa, Ont.
o Institute for Research in Construction	Ottawa, Ont.
o Division of Mechanical Engineering	Ottawa, Ont.
o Institute for Marine Dynamics	St. John's, Nfld.
TRANSPORT CANADA	Ottawa, Ont.
o Canadian Coast Guard	Ottawa, Ont.
o Transportation Development Centre	Montreal, Que.

Private Sector-based R&D

The Natural Sciences and Engineering Research Council (NSERC) funds university-based R&D through research grants to faculty members and scholarships to students.

The federal government supports industrial R&D through a series of mechanisms, for example the Industrial Research Assistance Program (IRAP), the Industrial and Regional Development Program (IRDP), and the Unsolicited Proposals (UP) Program. The latter gives support to unique R&D proposals submitted from the private sector. Furthermore, the government also provides tax incentives for industrial R&D through write-off provisions and tax credits. It is stressed that these programs apply to the industrial sector in general; none is directly aimed at developing arctic technology.

SPECIAL PROGRAMS

Departmental science programs have evolved over several decades in response to government requirements as perceived at the time. However, the rapid pace of northern development, particularly the quest for arctic hydrocarbon resources since the late 1960s posed unprecedented challenges to government agencies. As a result, new R&D programs were required to support government policy initiatives and to strengthen the government's ability to regulate and manage the megaprojects that were planned. The principle programs in this category are shown in Table 2. Common to all programs is that they have (or had) specific purposes, are limited-time programs, and are closely co-ordinated by interdepartmental committees. Also, private sector advice is sought on the design and implementation of each program and industry-government co-operation on individual studies is common. The scientific expertise of the line departments is however, essential in planning and conducting these studies.

It is federal government policy that the resource industry is responsible for the R&D needed to solve the technological

TABLE 2

Special R&D Programs

Program	Purpose	Cost/year(s)
Panel On Energy R&D (PERD) (EMR)	R&D related to all energy forms	$19.2 million per year for oil and gas related issues
Northern Oil and Gas Action Program (NOGAP) (IAND)	To enhance government preparedness to regulate northern hydro-carbon developments	$11 million per year
Environmental Studies Research Funds (ESRF) (EMR/IAND)*	Funding R&D related to decision-making on environmental aspects of oil and gas activities	$2-6 million per year
Arctic Marine Oil Spill Program (AMOP) (DOE)	To develop technology to enhance contingency response capability	$11 million since 1977
Frontier Geoscience Program (EMR)	Geological surveys of continental margins	$15 million per year
Beaufort Sea Environmental Monitoring Program (BEMP) (IAND)	Monitoring of critical environmental effects of development activities	
Arctic Marine Research Program (1981-86)	To enhance Arctic shipping technology	$26 million over 5 years

* Financed by oil and gas industry; administered by federal government.

problems and to obtain the information required to evaluate plans for individual development projects. The government role is to ensure that appropriate expertise and knowledge-base are available within government agencies to provide the policy framework to guide the development activities. An appropriate and effective regulatory system including codes and standards is an important component of such a framework. Standards and codes are usually developed in co-operation with the Canadian Standards Association or the Canadian General Standards Board.

This broad definition of industry and government responsibilities has led to heavy emphasis in industry on short-term R&D aimed at specific solutions. Government programs supplement this by stressing longer-term R&D projects and by funding projects related to policy and regulatory issues and those that would benefit a wider group rather than only one sector, for example the oil and gas industry. Some recent studies related to health and safety and studies of broad - often global - environmental issues, such as climatic change and stratospheric ozone, are in this category.

SPECIFIC RESEARCH ACTIVITIES

Among the many current R&D activities, the following may be of particular interest and warrant special comments:

- Amauligak development
- Ice scour
- Polar 8 icebreaker
- Arktos
- Ice island program
- Radarsat
- Centre for Frontier Engineering Research

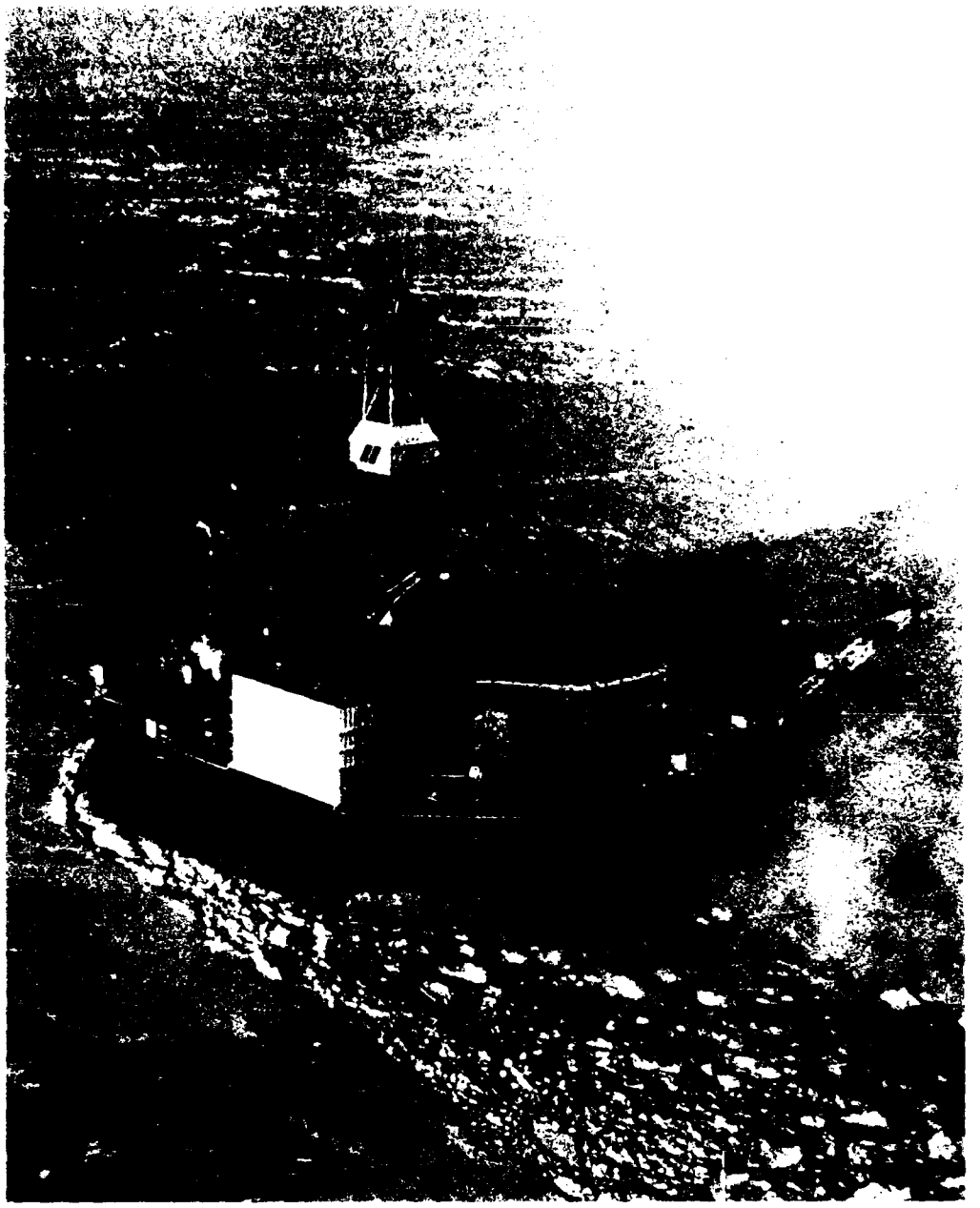

Figure 2. Molikpaq drilling platform at Amauligak site.

[illegible] plan to develop this [illegible] water depth, at 42 m (Fig. 2). Production [illegible] at least 20–30 years, much longer than [illegible] evaluate the new design.

requirements, government agencies have initiated several studies such as hindcast studies on waves and currents; geotechnical studies to evaluate protection requirements for buried pipelines; and studies of ice pressures on structures and of sediment characteristics in sand filled, bottom based berms.

Ice Scour

Scouring of the sea floor by sea ice and icebergs has become a major issue in connection with offshore hydrocarbon development in the Beaufort Sea and on the shelf off Labrador and Newfoundland (Fig. 3). Data collected from surveys in the Beaufort Sea are stored in computerized data bases on scour characteristics and locations, which has greatly improved our ability to analyse statistically the temporal and regional distribution of scour features.

Figure 3. Ice scour marks from southern part of the Beaufort Sea.

The Dynamics of Iceberg Grounding and Scouring (DIGS) project under the auspices of the Atlantic Geoscience Centre includes detailed studies of the interaction between icebergs, the currents, and the wind regime that drives them, the geotechnical characteristics of the sea floor and the nature of the impacts. Field studies have been done on the Labrador shelf, but fossil scours formed by icebergs in ancient ice dammed lakes in central Manitoba have added to the understanding of the process.

Polar 8 Icebreaker

The resources of the Canadian Arctic will be developed and icebreakers and marine shipping will be an integral part of this process. To enhance our ability to operate effectively in arctic waters, the federal government decided recently to construct the world's most powerful icebreaker, the Polar 8. Scheduled for delivery in late 1992, it will have excellent facilities for support of research in many scientific disciplines. A special committee will be formed to plan and co-ordinate the science programs for the new vessel. The design of the vessel is based on several years of research including that funded under the special Arctic Marine Research Program.

Arctic Escape System (AES) - Arktos

Federal support to Watercraft Offshore Canada contributed to the successful development of the company's prototype of Arktos - an amphibious, self-righting, tracked, escape vehicle that can be used for emergency evacuation from offshore drilling platforms and ships in ice (Fig. 4). The amphibious vehicle has dual power systems, with tracks for use on land or on ice; water jets for use while navigating in water. The vehicle is capable of crossing open and ice-filled leads, climbing onto ice sheets, and crossing pressure ridges and rubble fields around offshore drill sites. Further development is underway to adapt it as a multipurpose service vehicle for use on ice breakers.

Figure 4. Arktos in ice-filled lead. Each unit is about 5.4 m long, 3.6 m wide, and 2.7 m high and seats 25 persons (photo by Captain D. Johns).

Ice-Island Program

The Canadian Ice Island Drift Program was initiated in 1983 when instruments were placed on an island that had broken off from the Ward Hunt Ice Shelf on Ellesmere Island during the previous year. The island has a runway, of more than 1000m and the camp facilities for 30 persons are used as a field laboratory by a wide range of arctic scientists (Fig. 5). It is anticipated that the island will follow a drift path roughly similar to that of the ice island T-3 and will be occupied for several years adding greatly to our understanding of arctic phenomena.

Radarsat

In co-operation with several other countries, notably the United States and the United Kingdom, Canada is now planning the construction, launch, and operation of Radarsat (Fig. 6). The principal sensor will be a synthetic aperture radar (SAR) that can operate in several modes and provide all-season,

Figure 5. The 5- by 3-km ice island with camp and airstrip (photo by G. Hobson).

all-weather, global surveillance. Operating in a polar orbit it will provide excellent coverage of high-latitude regions and any location north of latitude 72°N will be covered at least once daily. Surveys of sea-ice conditions will be a major, but not the only use of the satellite. Radarsat - scheduled for launch in 1994 - represents a major commitment on the part of Canada to participate in international space programs.

Centre for Frontier Engineering Research (C-FER)

The federal government recently gave a $7.75-million grant to C-FER, a nonprofit research centre that will expand its current facilities in Edmonton. New multimillion-dollar test facilities will be constructed and will contain two laboratories; the low-temperature structural laboratory and the tubular products laboratory. Research in the laboratories will aim at developing technology that will lower the capital and operating costs of frontier energy developments.

Figure 6. The future Radarsat.

FUNDING LEVELS

Because arctic research is carried out as a part of national programs, obtaining accurate information on expenditures on arctic science is difficult; there is no easy way of dividing program and infrastructure costs between the Arctic and non-Arctic components. Furthermore, modelling and laboratory experiments aimed at resolving northern problems and understanding northern issues are often done outside the Arctic. However, the Canadian effort in arctic research amounts to many millions of dollars every year.

CURRENT POLICY ISSUES

Two Canadian policy developments will influence the future of arctic research in Canada. The first is the recent science policy initiative of the federal government; and the second is a review of Canada's role in polar science, led by the Minister of Indian Affairs and Northern Development.

National Policy for Science and Technology

Developed by the federal government in co-operation with the provinces and territories, a national policy for science and technology was announced in 1987. It stresses the need for increased R&D spending; increased efforts to promote technology transfer; and raises the profile of science and technology in the future economic and social fabric of the country. A $1.3-billion, five-year program to strengthen the universities through scholarships and support of centres of excellence was announced recently.

A key element in the policy is to encourage private sector participation in R&D. The Government of Canada has, for years, insisted that as far as possible R&D should be performed by the private sector through contracts. The new policy seeks to increase private sector funding as well as performance. It also seeks to promote government-industry-university partnerships in R&D to capitalize on the unique capabilities of each sector.

Canada and Polar Science

The Honorable D. Crombie, Minister of Indian and Northern Affairs, wanted to examine the idea of establishing a "National Polar Institute for Canada" and asked a small working group chaired by Dr. Fred Roots to study the proposal and to make recommendations. Their report, Canada and Polar Science was published in 1987. The Minister accepted the report as a whole and endorsed its recommendations.

One recommendation calls for the establishment of a Canadian Polar Research Commission to improve co-ordination and

effectiveness of Canada's arctic research. Further, it suggests that Canada besides being a major player in the North also has a role to play in Antarctic matters and should, therefore address itself not only to arctic issues but also to broader polar issues. Such a commission would also serve as a point of contact for similar groups from other countries. The need for this is increasingly evident in view of emerging circumpolar co-operation on arctic R&D. Means of implementing this recommendation are now being examined.

SUMMARY

The Government of Canada supports a variety of Arctic R&D programs, most of which are closely related to the government mandate to provide regular government services throughout a vast territory. This mandate ensures a relatively stable funding level as opposed to industry-sponsored R&D. A significant amount of arctic R&D has recently been funded through special programs aimed at addressing new problem areas. The development of arctic technologies is essentially left to the private sector with financial support from the government. However, technology transfer is a priority with the government and close liaison is encouraged between the industry, university, and government sectors.

The government has a long-term commitment to arctic R&D and initiatives such as the Polar 8 icebreaker and Radarsat will open new opportunities for arctic research in the future. Encouraging initiatives have recently been taken to establish a Canadian Polar Research Commission to co-ordinate these activities.

DANISH ARCTIC SCIENCE AND ENGINEERING

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Introduction

We appreciate very much the invitation to present a paper about Danish arctic science and engineering here at the "Offshore Mechanics and Arctic Engineering Conference".

As you may know, engineering under arctic conditions has deep roots in the Nordic countries. One of the oldest ruins in North America you will find in Greenland - a church built by the Vikings around year 1200 in the South of Greenland.

Hvalsey Church ruin at Qaqortoq is the best-preserved ruin in Greenland from the Norse period.

Engineering and construction are at present based more upon experience than research and comprise modern dwellings including sewerage and water supply, factories, airports, habour quays, and construction on the Greenland Ice cap.

Arctic construction runs into problems similar to those in other areas, but in one matter, arctic technology is quite different. Common for all arctic construction is that the activities have to be totally self-supporting. This demands of course a very high degree of planning and arctic logistic knowledge.

Commission for Scientific Research in Greenland

The modern technological development in arctic areas calls for multidisciplinary research. To meet this demand, the "Commission for Scientific Research in Greenland" was set up by the Danish Government in 1878 as a permanent commission. Members of the Danish Commission for Scientific Research in Greenland are representatives of the Danish State Research Councils, of the Home Rule Parliament, the Greenland Department of the Danish Prime Minister's Office, the Geological Survey of Greenland, the Greenland Fishery Rsearch Institute, the Greenland University and the Greenland National Museum. The tasks of the Commission are to draw up priorities for the distribution of government funds allocated to Greenland research, coordinating Danish and foreign research activities in Greenland, acting as instigator to new research projects, advising Danish authorities and other interested parties on research questions concerning Greenland, and disseminating information about research activities in Greenland.

The Commission publishes "Meddelelser om Grønland" - MOG - , divided into "Bioscience", "Geoscience" and "Man & Society", containing dissertations covering all fields of research in Greenland. It also publishes a Danish/Greenlandic magazine "Forskning i Grønland/ tusaat" (Research in Greenland) as well as a Newsletter in English.

Old and new housing in Godthaab (Nuuk). Photo: Jorgen Taagholt

Greenland, the world's largest island, got Home Rule in 1979 but remains a part of the Kingdom of Denmark. The Home Rule Authorities are responsible for internal matters but the Danish Government remains responsible for foreign relations and the defence of the Realm. With respect to natural non-living resources, the Home Rule Act, with acknowledgement of the fundamental rights of local populations, established a joint Danish/Greenlandic political commission with equal representation and right of veto for both parties concerning mineral resources. The daily management is assigned to the Mineral Resources Administration for Greenland under the Danish Ministry of Energy.

International Cooperation

The research activity in Greenland today comprises about 100 individual research projects a year. All new projects have to be presented for the Commission for Scientific Research in Greenland and for scientific and operational evaluation prior to the start of the field work in Greenland, and the Commission informs the local Greenlandic Authorities about the planned activity and the restrictions in force. About 1/3 of the individual projects are Danish conducted mainly by Danish universities and 2/3 are foreign; therefore, international coordination and cooperation are needed. In addition to the individual projects, Danish/Greenlandic governmental applied research institutions (Geological Survey of Greenland, the Greenland Fishery Research Institute, Danish Meteorological Institute, Danish Geodetic Institute, etc) conduct comprehensive activities in Greenland each year.

Today, there is a growing national and international interest in the polar regions. These regions are of special importance because of their great strategic and scientific value as well as their natural resources. The regions are currently the object of a series of costly international research projects that cover several scientific and technological disciplines. The results of the research will have a decisive influence on many fields in coming years. In this connection, we can stress climatic research which is of great significance to the environment of the Earth in future. It is important that these scientific results are made known to large circles all over the world.

Today, a series of countries, Norway, Sweden, West Germany, Holland, Great Britain and the Soviet Union, to name some, have established polar institutes or polar secretariats where the particular country follows the development in the Arctic, especially the scientific and the technological developments and informs national circles of the situation.

At present, the Commission for Scientific Research in Greenland participates substantially in the international discussion concerning the establishment of a non-governmental, International Arctic Science Committee open to all countries involved in arctic science.

Danish Polar Center

At national Danish/Greenlandic level, the Commission for Scientific Research in Greenland and the Society for Arctic Technology will play an important role. The Danish Government plans to set up a Danish Polar Center housing such Danish arctic institutions. This development must be seen in the light of the closing down of the Ministry for Greenland and the transfer of its activities mainly to the Home Rule Government but also to other Danish ministries. The growing international cooperation has brought about a steady increase of the need for a Danish Polar Center which can represent Danish research efforts in the international arctic cooperation and which, besides the more scientific undertakings by the Commission, also can represent Denmark with respect to arctic industrial development.

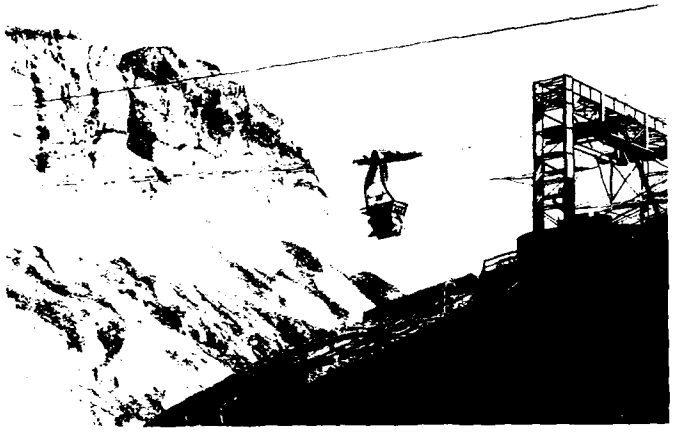
Geodetic and Geological Mapping

A condition for modern development in Greenland is the activity conducted by the Danish Geo-

detic Institute making the needed geodetic mapping, a huge task, although modern position determination using satellite and logistic support from aircraft and helicopter today makes the task manageable. The logistic support for this task is cross utilized for the general geological mapping of Greenland conducted by the Geological Survey of Greenland, as well as for mineral and energy exploration.

Exploration and Exploitation

At present six permissions for prospecting license and 17 concessions for exploration are in force and in addition two for exploitation. The unique deposit of cryolite at Iviqtut in South Greenland is now exhausted after a production of some 3,5 million tons since industrial production started in 1856 as one of the first mines in the Arctic.



Transport of ore from the lead and zinc mine to the processing and shipping area at Marmorilik. Photo: Jorgen Taagholt

Since 1973 a production of lead, zinc and silver has taken place at Maarmorilik. After 16 years of production, the main deposit in the Black Angel Mt., 700 m above the fjord, is empty. However new, smaller but richer deposits under the Ice cap might form the basis for production in the coming years. Unique drilling for mineral resources through the Greenland Ice cap has been an unusual challenge for Danish engineers.

The Geological Survey of Greenland, as advisory body for the Mineral Resources Administration for Greenland, has produced a map showing known mineral deposits in Greenland which virtually has all major minerals that according to the US Bureau of Mines will be lacking for industry by the year 2000. However, world wide technological development can rapidly change the demand. Production of new superconductors and technical ceramics might form the basis for quite new mining activities in Greenland.

Due to transportation cost, it is preferable to export metal or advanced metal alloy instead of concentrates from arctic deposits, and environmental concern at European processing industry might promote relocation of such processing industry to arctic areas with low population density and at the same time rich in raw materials including clean hydroelectric power needed for mining and processing the ores. But so far no plans exist for processing industry in Greenland and the present world market prices do not encourage further evaluation today.

Hydroelectric Power

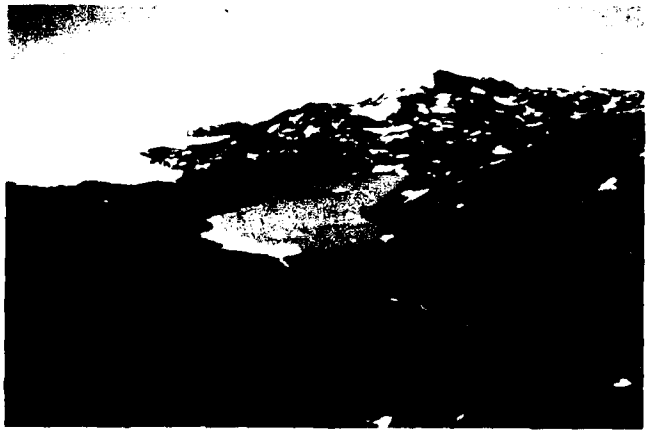
For many years it has been appreciated that hydro-electric power production in Greenland is possible. Heavy annual precipitations combined with favourable topographical conditions open possibilities for hydro-electric plants. Till now there has been no local demand for large amounts of energy in Greenland, and consequently there has been no incentive to invest in hydro-electric power stations.

However, since the energy crisis in 1973, interest in making use of the arctic water reserves has grown and natural basins located in bed rocks at the edge of the Greenland Ice cap at 200-700 m above sea level close to the fjord system open excellent possibilities; drafts have been made for 16 power stations in West Greenland with estimated yearly production ranging from 100 GWH to 1000 GWH. The draining areas are rather limited but years with low precipitation give more clear sky and melting from the ice thus compensating for lack of precipitation.

In recent years comprehensive glacier-hydrological, geological and meteorological investigations have taken place in order to map the technical and physical possibilities of setting up hydro-electric plants. Particular interest centres around the extensive basin areas off the settlements that can be reached by sea, where the power stations might provide energy e.g. for use in mining and production of fertilizers or aluminum, and round basins close to settlements which might form the basis for local energy supply. Some minor hydro-electric plants have been placed in operation at local settlements during the past few years.

MINERAL RESOURCES IN GREENLAND

Metallic resources	Industrial minerals	Precious stones
aluminum	coal	blue sodalite
antimony	cryolite	cancrinite
arsenic	feldspar	cordierite (dichroite)
barium	fluorine	feldspar (amazonite)
beryllium	graphite	- (moonstone)
cerium	marble	garnet
chromium	olivine	grønlandite
copper	phosphorus	jasper
gold	soapstone	kornerupine
iron	sulphur	lapis lazuli
lanthanum		nuummite
lead		quartz (rock crystal)
molybdenum		- (smoky quartz)
nickel		- (agat)
niobium		- (calcedony)
platinum		ruby
silver		saffirine
strontium		tourmaline
tantalum		tugtupite
tin		
titanium		
tungsten		
uranium		
zinc		
zirconium		



Nordbosø in Johan Dahl Land ca. 25 km north of Narssarssuaq is being further explored with a view to hydro-electric power schemes. The lake, which is situated at 660 m above sea level, drains a precipitation area of 150 km^2 and a melting area of the ice-cap covering 35 km^2. The annual volume of water leaving the lake is presumed to be able to form the basis for a production of energy totalling some 225 million kilowatt-hours per annum, corresponding to twice the present consumption of electricity of Greenland. Photo: Jørgen Taagholt

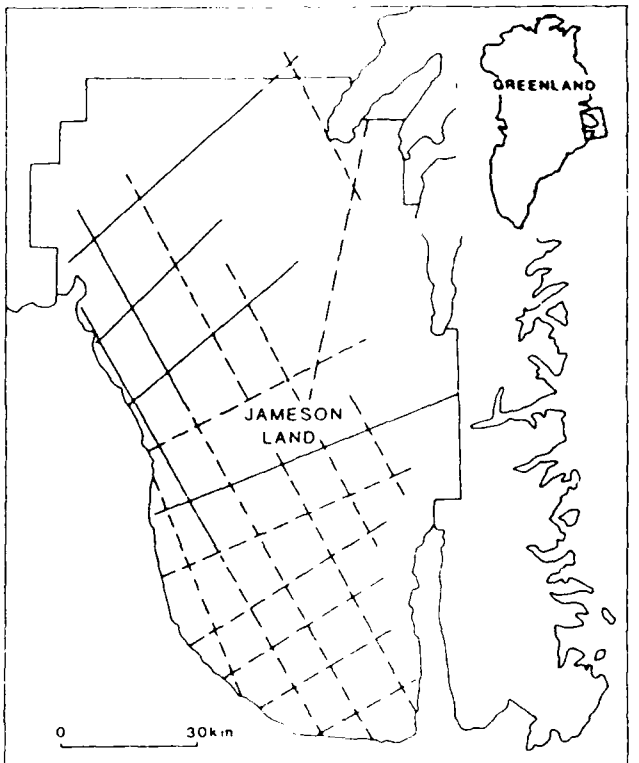
In recent years, studies have been conducted of the melting of snow at the Ice cap, the generation of lakes and river systems at the Ice sheet and the study of the uncontrolled sub-glacial outflow. Radar measurements of the bed rock topography define the water sheets, and during 1987 maps have been produced of some regions showing stable river systems at the Ice Sheet. If the outflow from the melting at the Ice cap can be guided to the bed rock lakes which form the basin for power plants, the energy production might be increased substantially.

Oil and Gas Exploration

Greenland and its surrounding continental shelf are potential areas of oil and natural gas resources. At present, a consortium of three companies - ARCO Greenland A/S, a Danish company which is a subsidiary of the Atlantic Richfield Company, Los Angeles, Arktisk Minekompagni A/S, a private Danish company, and Nunaoil A/S, a public company owned by the Danish Government and the Greenland Home Rule Authorities, each with 50% of the shares in Nunaoil - holds a concession which requires that the operator collects 1500 km of seismic profiles of Jameson Land in Central East Greenland before the end of 1990.

Although ARCO must be considered one of the companies which has the greatest experience in oil exploration under extreme, arctic conditions, ARCO finds the Jameson Land activities very challenging. The Mineral Resources Administration is responsible for the overall supervision of the activity. To preserve the tundra and the sparse vegetation from traffic when snow cover is lacking, helicopters will fly in the heavy loads and fuel depots from the base camp with airstrip at Constable Pynt. During the summer period the investigations are carried out with drilling equipment flown in by helicopters. The drilling equipment is used in the drilling of short holes for small explosions necessary for seismic investigations. As soon as there is adequate snow cover, vibroseis vehicles can start their activities.

REGIONALT SEISMISK PROGRAM (CA. 1100km)



Jameson Land concession area, with location shown on inset map of Greenland. Sites for seismic exploration are indicated by the broken lines.

GGU Feb 1987

Environmental Concern

In the continuing environmental programme, Danish/Greenlandic Governmental applied research institutions are strongly involved in this activity learning how to manage human, biological and technical problems related to such exploration activity. The Greenland Technical Organization (GTO) has to assure human safety for workers involved in making regulations concerning fire, energy supply and oil spill, sea and land transportation and avalanches. The Greenland Environment Research Institute is mapping the hunting areas, the breeding areas for birds and animals, and the sensitive forage areas of important vegetation with respect to setting up restrictions to minimize the environmental impact. For the said Danish/Greenlandic Authorities, it is an important task to gather as much information, insight and experience as possible in order to obtain the competence needed for the preparation of the technical, environmental and human safety regulations with respect to further development in Greenland.

Oil-related geophysical activity

The Mineral Resources Administration wants, at present, to utilize the situation of low activity related to oil exploration to establish a better basis for decision-making of future oil activity in Greenland. Accordingly, a six-year programme is planned for basic oil geological investigations on the Greenland continental shelf. The so called KANUMAS Project comprises some 22 000 km seismic mapping of the entire Greenland offshore area with exception of those areas which, as a result of aeromagnetic and seismic surveys earlier completed, are considered without interest.

The operator of the planned seismic programme is Nunaoil A/S while the technical management will be conducted by the Geological Survey of Greenland in close cooperation with the international oil industry. The programme includes approximately 8 500 km of seismic profiles of the East Greenland shelf. Most of the East Greenland offshore to be investigated presents a marine environment of storis - packice, ice floes and icebergs in swift current most of the year. The activity is, therefore, limited to periods when the ice conditions allow ship operation. A part of this region, consisting of 100 000 km^2 shelf north of 73°N, seems to be the most geologically interesting and it is practically inaccessible. One favourable ice year every six years is the best one can hope for, and an icebreaker or an ice-breaking seismic vessel will perhaps be needed for these waters.

Sub-sea Facilities

Off Brazil some "sub-sea completion" already exists today for oil production. Some international technical experts expect that arctic sub-sea oil drilling facilities will be placed in operation about the turn of the century.

A group of Danish companies has just completed a study of sub-sea systems for Danish waters. It is important for Denmark and Greenland that Danish engineers follow the development carefully. Transfer of knowledge concerning Arctic sub-sea systems might be obtained through joint venture activity between Danish and international companies and Danish institutes or universities with special or local expertise. If the basic oil geological investigations indicate favourable conditions in the northeast Greenland shelf, ocean floor installations for oil drilling are needed due to the surface ice conditions. Such installations are a great challenge to arctic engineers. Arctic sub-sea facilities do not require huge structures because the structure will not be exposed to environmental surface forces - wind, waves, icing, current and ice drift - and may well be less expensive while other components and access to the facilities will be more complex and costly than for surface facilities. Concerning the North Greenland continental shelf, sub-sea, sub-surface facilities might be the technique usable due to the heavy ice conditions.

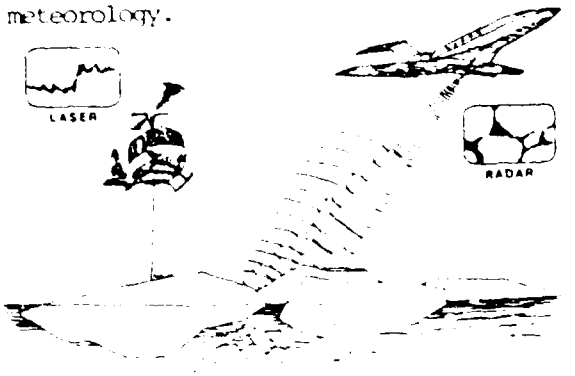
Greenland Ice Branch

From a glaciological point of view, Greenland is rather unique. The drifting Polar Sea ice - storis - together with the local-produced huge icebergs ranging up to 175 m above sea level are a hazard to all navigation.

Since 1870 the Greenland Ice Branch of the Danish Meteorological Institute has gathered information on the occurrence of sea ice in the Greenland water and for many decades, the Greenland Ice Branch was the international centre for arctic ice conditions. At the Greenland Ice Center at Narsarsuaq, information from ships, helicopters, aircrafts and satellites are retrieved and analysed daily.

Eight Danish research teams are involved in Danish and international studies such as Marginal Ice Zone Experiment (MIZEX), East

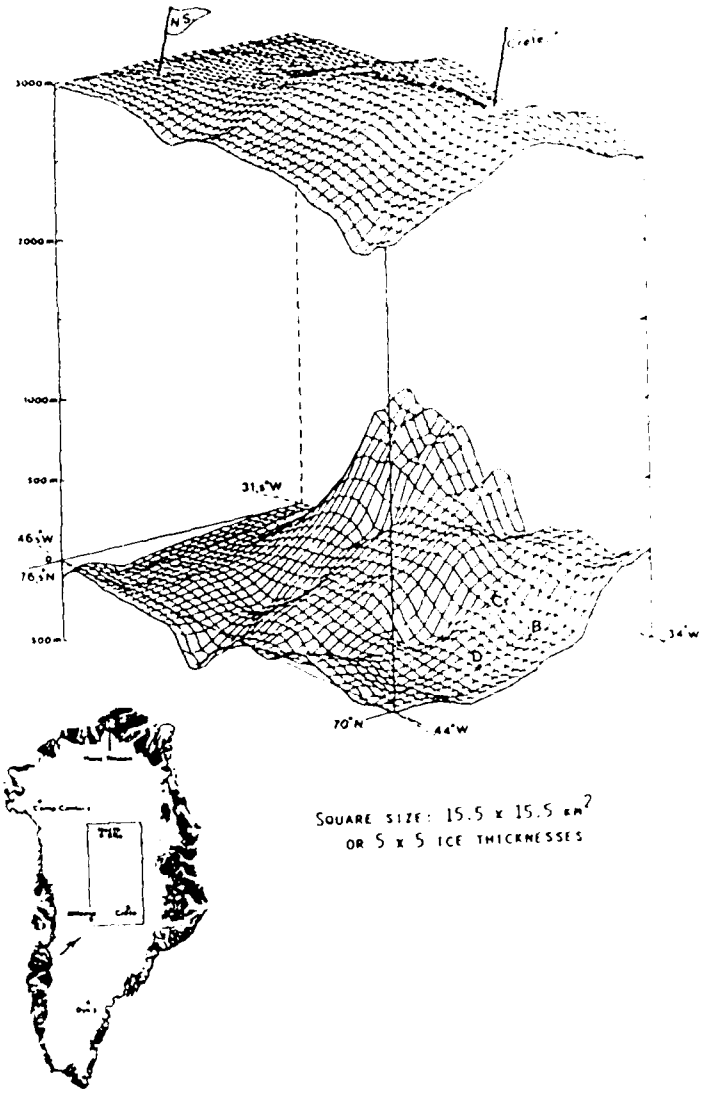
Greenland Current Project and the Greenland Sea Project, all comprising meteorological, oceanographical, glaciological and biological programmes. As part of the programme, a Danish group is trying to develop 3-dimensional numerical models to describe the oceanographic phenomena, the ice kinematics and meteorology.



Remote sensing

Remote sensing from either aircraft or satellite plays a still more important role with respect to geological, biological and geodetic mapping, guidance for sea navigation including meteorology and ice drift and for environmental surveillance. In the Danish remote sensing project, the newly developed methods will be exploited to handle the large time series of data that will be available from existing or planned satellites including methods to handle data from the synthetic aperture radar and the imaging microwave radiometres on the European Space Agency's ERS-1 satellite.

Remote sensing is also used with aircraft as platform e.g. for mapping the bed rock topography below the Greenland Ice cap. With Danish built radio echo sounding equipment and the use of American C-130 aircraft, US and Danish scientists have produced a topographic map with a 15 km grid spacing over the total subglacial bed rock below the Greenland Ice Sheet. More detailed mapping of the subglacial bed rock topography has in recent years been conducted by the Geological Survey of Greenland with use of a 300 MHz radar installed in a Jet Range helicopter. Such maps are of importance to define the watersheds which are of importance to calculating subglacial water outflow from the Ice cap. This outflow could form the basis for hydroelectric power production in Greenland as earlier mentioned. With future superconductors it might be possible to export electricity from Greenland to the North American continent.

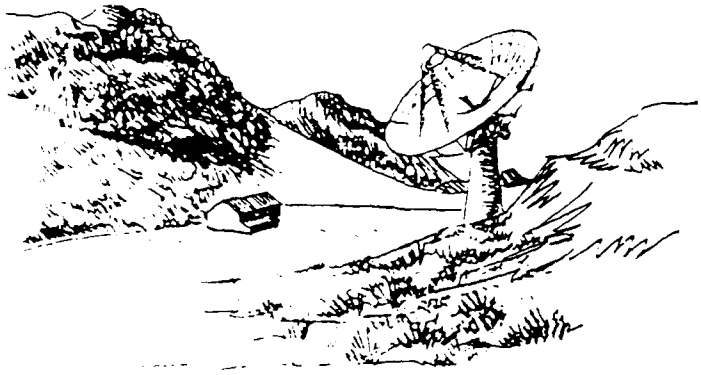


Greenland Ice Sheet Program

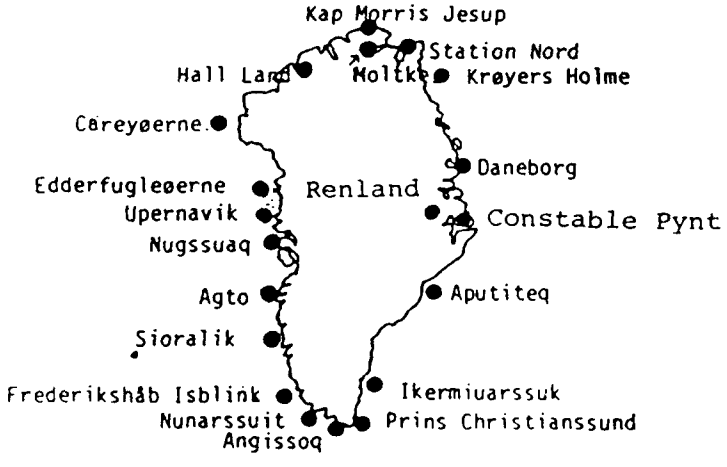
The mapping of the bed rock topography based upon remote sensing using 60 MHz Danish built radar is of importance to the Greenland Ice Sheet Program (GISP) in which researchers from USA, Switzerland and Denmark have conducted deep drilling down to the bottom of the Ice Sheet more than 2 km below surface,corresponding to some 100 000 years of precipitation. Such deep drilling gives important information about the Ice Sheet dynamics and analyses of the ice cores have given historical information about weather,climate, pollution and environment in former times. Specialists involved in the study of future climatic changes have made important deductions from the ice core data, as for instance, the risk of climate change due to volcanic eruption or to increased air pollution.

Geophysical measurements

Due to the geophysical location near the Earth's geomagnetic pole, Greenland has a unique chain of geophysical observatories which conduct geomagnetic recordings, auroral observations, ionospheric and particle precipitation measurements in the area from the magnetic pole to the auroral zone. Besides these groundbased activities, measurements of importance to radiowave propagation are additionally conducted by means of balloons, rockets and satellite-borne sensors. Such investigations are of importance also to the industrial development and have opened up for the possibility of e.g. advance high accuracy position determination



navigation system, real time transfer of geophysical data including meteorological data from unmanned stations in the ARGOS-system, increased personal safety thanks to the successful COSPAS/SARSAT system besides more traditional telecommunication facilities.



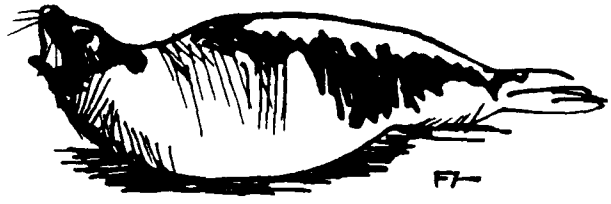
Automatic Weather Stations

Marine environment

All through history, the arctic people have based their traditional life on the marine living resources. Accordingly, marine biological investigations are of vital interest from an economic as well as a scientific point of view. Many species live in Greenlandic sea under marginal conditions where climatic oscillations might be crucial.

Since 1979 Danish scientists conduct a programme for systematic monitoring of content of heavy metal in the marine environment, especially of metal concentration in marine mammals which are the main part of the local diet in the hunter district. Such an ambitious project is of importance not only to the local community but also in relation to future industrial activity. It is important to know the natural level of pollution before a new activity starts, and it is important to have an understanding of the problems before the environmental agencies can set up regulations for such new activities. The problem is of a circumpolar nature and calls for international cooperation.

The marine mammals are depending on acoustic systems for communication and navigation. Today, rather good information has been gathered concerning noise in the sea, including information about ambient noise, man-made noise, noise-propagation and attenuation. Much more information is needed about underwater acoustics in the Arctic. The biological



aspect in the Arctic is a very important issue: How do marine mammals communicate and navigate using acoustic signals? How do the biological sensors work? A cooperation between biologists, underwater acousticians and radio-communication experts concerning the study of biological signal processing, filtering, and signal recognition in noisy environment is important. Such a multidisciplinary study must be performed before we can understand the bio-acoustic problems in the Arctic and the study is of importance not only to biologists but also to all planning of arctic transportation as part of industrial arctic development.

Man and Environment

Based upon archaeological discoveries and findings of human bodies (mummies and skeletons), a Danish multi-disciplinary research project, "Man and Environment - past and present", has recently been started. The project includes studies of several extraordinary, well-preserved mummified bodies from approx. year 1500 AD. Today the project includes studies of human remains ranging back to year 2000 BC. Such an examination gives important historical information about the environment of Man through centuries, information of importance for daily life in the Arctic and for evaluation with respect to impact on human life and for future industrial development.

During the last few decades remarkable environmental concern has grown from the "Green Movement". This concern has had a very positive effect, and our environmental consciousness is today an important factor in all arctic planning.

However, environmental concern should not be regarded as just a limiting factor for an increasing activity in the arctic region. A consistent, overall environmental policy could result in an attempt to advance industrial development in extensive arctic regions with extremely low population density. Naturally, great care must be taken not to damage the arctic environment, but an unspoiled arctic environment for the good of local hunters and visiting scientists at the expense of continued pollution for millions in the densely populated industrial centres presents a situation which requires careful consideration in relation to future industrial policy.

Power consuming industries such as the production of aluminum and fertilizer could perhaps be transferred from densely populated industrial centres to places in the Arctic that have rich potentialities of energy in the fact that hydro-electric power could be harnessed where at present water runs unexploited out into the sea. In this way, the global environmental situation for many could improve substantially, and new production plants - constructed so as to reduce pollution to a minimum - could be built where hydroelectric resources are available e.g. in the West of Greenland. Thus we could reduce the combustion of fossil fuel in the mass populated areas, economize on our resources and in general improve the environmental conditions. Critics will maintain that this will be to the damage of the arctic environment; but non-critical consumption of fossil fuel in other places results in a continued, increasing risk of interference in the global energy balance. with unpredictable climatic consequences perhaps especially in the arctic regions. An increasing exploitation of arctic, renewable energy resources as e.g. hydro-electric power could have a positive environmental effect seen from a world-wide point of view. An increased industrial development in arctic regions will give a more diversified commercial life of interest and importance to the local society.

An Arctic Dilemma

The small arctic nations, which are primarily Norway and Denmark, and to some extent Canada are confronted with an arctic dilemma; a dilemma which is not facing countries without arctic regions within their boundaries. Countries such as Denmark must give priority to applied research in their national budgets, whereas countries without arctic regions, but with interests in and traditions for arctic research, can concentrate exclusively on the more attractive scientific problems which may shed light on their particular scientific efforts as they do not have to earmark funds for the necessary but more routine accumulation of scientific data. The paradox of this situation is becoming more obvious as the integration of state-of-the-art polar science into global science is given greater and greater emphasis. In study programmes such as the World Climate Research Programme, the northern component is an essential, and perhaps the ultimate component of global studies.

This is why initiatives for advanced, polar research programmes are, and this is quite understandable, often launched by non-arctic countries; a situation which is causing problems in the small arctic countries. The Nordic countries and Canada would benefit tremendously by such research projects, but our researchers and scientists are often excluded from participation because of their above-mentioned "domestic obligations". The problems facing the small nations must be understood and the planning of international scientific collaboration must make allowances for the small nations' situation.

Demand for multi-disciplinary Scientific Cooperation

With reference to increased industrial development, the above mentioned activity in Greenland depends on a broad spectrum of polar research activities. One of the most important fields - which in connection with commercial industrial undertaking too frequently is overlooked - is extensive studies about the interaction of man, nature and industrial development.

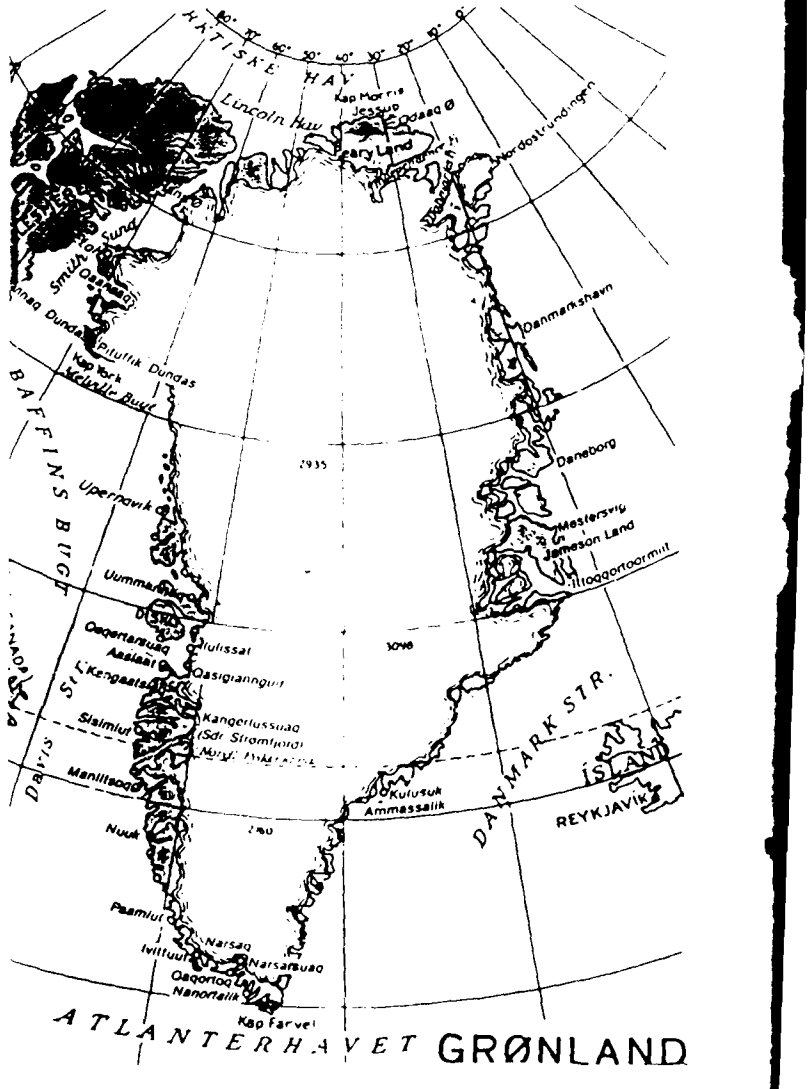
Engineers and administrators must understand that a harmonic, well-balanced development of arctic regions demands respect for local cultural traditions, for the sensitive arctic environment and it requires a close contact to local communities for information and discussion so that a close cooperation may be established. In order to achieve such a cooperation, it is very important to have the results of a range of social-economic studies and a range of multi-disciplinary scientific and technical investigations frequently conducted in international cooperation, lasting several years and involving a great number of scientific activities.

An International Arctic Science Committee

At an Arctic Rim Nation brainstorm seminar early 1987 a small task force with representatives from Canada, Norway and Denmark was asked to draft a proposal for the setting up of an international Arctic Science Committee. This draft, now published for discussion, proposes:

- A non-governmental scientific committee, provisionally called the International Arctic Science Committee, should be established to promote international cooperation in scientific research in arctic areas. The committee would serve the scientific interests of arctic countries and provide a forum for discussion and co-ordination of the research interests of any country involved in arctic science. It would have as its special responsibilities the facilitation of circumpolar studies and the linkage of arctic research to major advances in world science.

- Representatives of governments of arctic nations - countries with territories north of the boreal forest zone -, should discuss the feasibility of establishing a mechanism for regular, structured intergovernmental discussions and liaison on arctic science matters. The discussions would deal with matters of common interest, including the organization and administration of international arctic research programmes and the exchange of scientific results. Such discussions, comprising what might be called an Intergovernmental Forum on Arctic Science Issues, would supplement but in no way interfere with the various bilateral science arrangements presently in existence between arctic countries.



For Denmark, with our special position in the arctic area, it is natural that we are seeking to continue and promote arctic know-how through the establishment of the Danish Polar Center in near future. I expect that this center will be responsible for the co-ordination and integration of Danish arctic science and engineering with the future international scientific activity in the Arctic and hopefully ensure substantial Danish participation in international arctic-related scientific collaboration.

It is my hope that conferences such as "Offshore Mechanics and Arctic Engineering" and international cooperation make their contribution to a harmonious,well-balanced development of the arctic regions.

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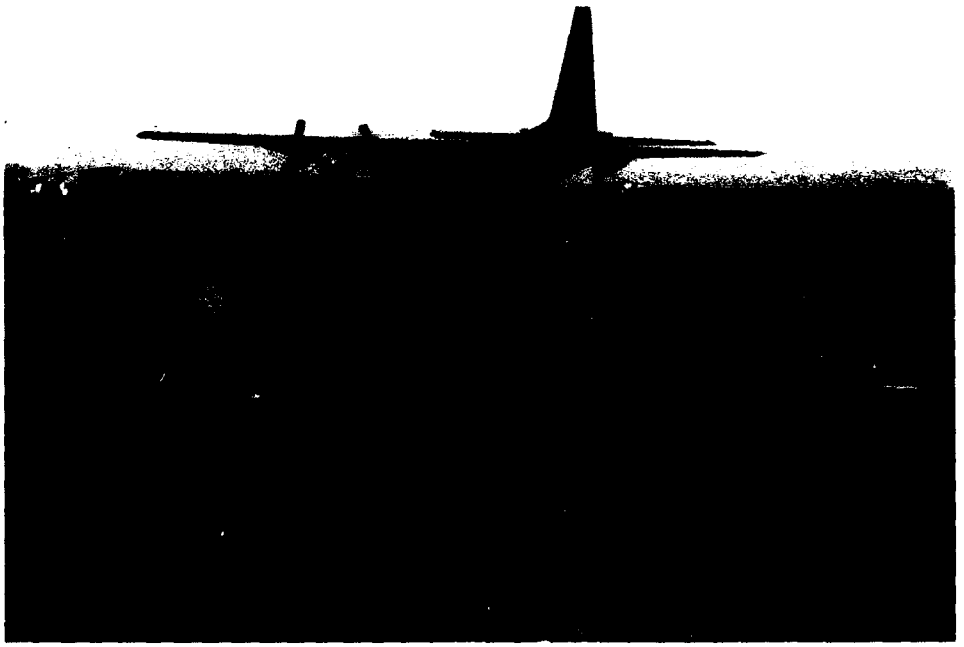


ARCTIC RESEARCH PROGRAMS IN SWEDEN

Rein Kommel

Swedish National Industrial Board (SIND)
Ocean Technology Program
Stockholm, Sweden

Contents

1. Sweden and its main advantages in arctic and subarctic R&D.

Sweden is a country situated in the northern parts of Europe with 8 358 000 inhabitants. Sweden extends from north to south at roughly the same latitude as Alaska and is approximately the size of New Jersey (Swedish geography, enclosure 1). The northern parts of Sweden

- have subarctic environment, severe climatic conditions and

- are above the arctic circle but still have developed infrastructure.

Offshore eastern Sweden lies the Baltic Sea, which is a shallow semienclosed, brackish water basin situated between latitudes 54^0 and 66^0 N. The northern part of the Baltic Sea is called the Gulf of Bothnia where severe ice conditions prevail in winter time. The gulf has been open for year round navigation since 1970 (map of the Baltic Sea, enclosure 2).

2. Centres where arctic and subarctic R&D is carried out.

2.1 Gulf of Bothnia:

The Gulf of Bothnia is an ideal test basin for technology to be used in arctic areas of the world. This has been recognized by the industry and sponsored investigations have been carried out in the gulf since many years. Several major projects are currently in progress or in a planning stage using this feature.

Ice forces against lighthouses
Two projects are in progress managed by the Swedish consulting company VBB AB and carried out in cooperation with Luleå University of Technology and the Swedish Meteorological and Hydrological Institute. The aim of the projects is to use lighthouses to obtain field observation data from ice - structure interaction. The projects are organized as joint industry studies with funding from international oil and construction companies and Swedish agencies mainly the Swedish National Industrial Board. The projects are:

- Ice forces against offshore structures - field observations and data analyses. Budget: 0.78 MUSD (three years) (4.70 MSEK)

- Field investigation of ice impact on lightweight aggregate concrete. Budget: 0.76 MUSD (three years) (4.54 MSEK)

A third project is in a planning stage:

- Field investigation of ice force distribution on offshore structures. Projected budget: 0.6 MUSD (three years) (3.6 MSEK)

BEPERS - 88
The Swedish Meteorological and Hydrological Institute, Chalmers University of Technology, the Swedish National Defense Research Institute and the Swedish Space Corporation have together with Finland initiated a major sea ice experiment in the gulf called:

- BEPERS, Bothnian Experiment in Preparation for ERS-1.

ERS-1 is a new European space satellite due to be launched 1990 and the main objective of BEPERS is testing ERS-1 similar sensors such as the SAR (Synthetic Aperture Radar) and radar altimeter for mapping brackish water sea ice. BEPERS is planned to be carried out March 5-10, 1988, in international cooperation between Sweden, Finland, Canada, the Federal Republic of Germany, the United States and Great Britain. Budget: 0.33 MUSD (2 MSEK)

2.2 Government institutions

Luleå University of Technology (LuTH).
LuTH is the world's most northern university of technology and is situated on the shores of the Gulf of Bothnia. One of its goals is to promote technology and industry in the northern cold regions of Sweden, partly above the arctic circle. At present the university has 800 employees, 3500 students and a turnover of 60 MUSD. Several departments are active within arctic research e.g. civil-, mechanical- and mining engineering. *Main areas of arctic* activity:

ICE Mechanical properties of ice, numerical modeling of stress and strains, ice forces, ice interaction with structures, load carrying capacity of floating ice covers, adhesiveness of ice to metal and polymer materials, frazil ice.

CONCRETE Concrete properties at low temperatures, ice abrasion, fatigue at low temperatures.

STEEL Welding at low temperatures.

SOIL Soil mechanics, freezing and thawing of soil. Permafrost.

LUBRICATION Lubrication (tribology) at low temperatures. Analyses and tests of various lubricants.

Available funds for arctic technology 1987/88 - 1.0 MUSD (6.0 MSEK)

Chalmers University of Technology (CTH)
CTH is a technical university in the city of Gothenburg and its marine technology department is the largest of the university system in Sweden. Within the Marine Structural Engineering program applied arctic research is carried out in cooperation with industry. The Remote Sensing Group of the Department of Radio and Space Science is concentrating on microwave remote sensing. Main areas of arctic activity:

ICE INTERACTION Computer analysis of interaction between ice and floating structures for arctic waters.

RADAR TECHNOLOGY Sea ice parameters derived by synthetic aperture radar and radar altimetry. Participation in BEPERS-88.

Available funds for arctic technology 1987/88 - 0.067 MUSD (0.4 MSEK)

SSPA Maritime Consulting AB
SSPA is a governmental owned consulting company also performing funded research programs within offshore and shipping, where the arctic activities can be found. Main areas of arctic activity:

ICE INTERACTION Interaction between icebergs and structures. Model- and field tests, simulations and mathematical modelling.

ICE NAVIGATION Manoeuvrability in ice and ice reducing methods in harbours. Simulations, model and field tests.

OIL SPILL Oil spill recovery technics in ice infested waters. Laboratory and field tests.

Available funds for arctic technology 1987/88 - 0.067 MUSD (0.4 MSEK)

Swedish Meteorological and Hydrological Institute (SMHI)
SMHI is a central government agency with responsibility for meteorology, hydrology and oceanography in Sweden. As such its position is unique: three disciplines closely inter-related under one roof. Advanced techniques and research are fundamental to SMHIs activities. Main areas of arctic activity:

RESEARCH Remote sensing in sea ice mapping, ice dynamics, ice models, data bases.

OPERATIONAL Ship routing in ice, sea ice surveillance, -forecasting, climatology and -statistics in the Baltic Sea and the arctic oceans north of Europe.

Available funds for arctic technology 1987/88 - 0.13 MUSD (0.75 MSEK)

Swedish State Power Board (Vattenfall)
Vattenfall is a government agency responsible for approximately 50% of the total hydro power capacity in Sweden, which is 60 TWH/year. (Total power generation, including nuclear power, is 135 TWH/year) Most of its generating facilities are situated in subarctic environment. Ice related research is carried out at the laboratory in Älvkarleby. Main areas of arctic activity:

ICE MANAGEMENT Ice jamming, frazil ice, computer models for river freeze up.

CONSTRUCTION IN PERMAFROST Rock tunneling and embankment dams (in cooperation with VBB AB).

Available funds for arctic technology 1987/88 - 0.1 MUSD (0.6 MSEK)

Swedish National Defence Research Institute (FOA)
Research required for the Swedish defence is mainly carried out by FOA who's activities cover wide fields in chemistry, medicine, physics, information technology, sociology and behaviour science. Even if most of the research is performed on behalf of the defence, part of it is commissioned by the civilian community. Main area of arctic activity:

RADAR TECHNOLOGY Icerad - a coherent pulse-doppler radar system for arctic shipping. SAR-processing facilities in preparation for ERS-1. Participation in BEPERS-88.

Available funds for arctic technology 1987/88 - 0.033 MUSD (0.2 MSEK)

3. Companies active in arctic technology

Several Swedish companies are active in arctic technology and have in-house research programs. It has however nöt been possible to get information about their R&D budgets and commissions.

3.1 Areas of activity

Design and construction of offshore structures:
- VBB, Skanska, ABV, Götaverken Arendal (GVA)

Arctic shipping:
- Broströms, Stena

Shipyard:
- GVA: Icebreakers, semisubmersibles, offshore structures

Consulting:
- SSPA, VBB, GVA

Exploration in arctic areas:
- Polargas

Miscellaneous
- ASEA Hägglund: Tracked vehicles, Cranes
- Skega: Icing on structures

4. Government agencies funding arctic and subarctic R&D

4.1 Swedish National Industrial Board (SIND)

SIND is a branch of the Swedish Ministry of Industry and operates within Sweden to:

- promote profitable industrial production
- strengthen the long-term competitivness of Swedish industry
- assist companies in adapting to changes in business environment
- balance regional growth and employment

SIND operates with four units; research, industrial restructuring, industrial development & financial incentives and small business development.

The industrial restructuring unit offers financial support, advice, consulting and other services in several areas of industry, one of these areas is the ocean industry. The Ocean Technology Program covers the following areas:

- arctic technology
- underwater technology
- survey technology
- offshore oil and gas

The overall aim of the program is to initiate development of new technology and further international cooperation. Support is given to high-risk projects in applied research, product development and international cooperation.

The following areas of arctic technology are to receive priority:

- ice interaction with structures
- systems, components and materials for cold climates
- instruments and scientific equipment for polar research

Available funds for arctic technology 1987/88 - 0.33 MUSD (2.0 MSEK)

4.2 Swedish Polar Research Secretariat

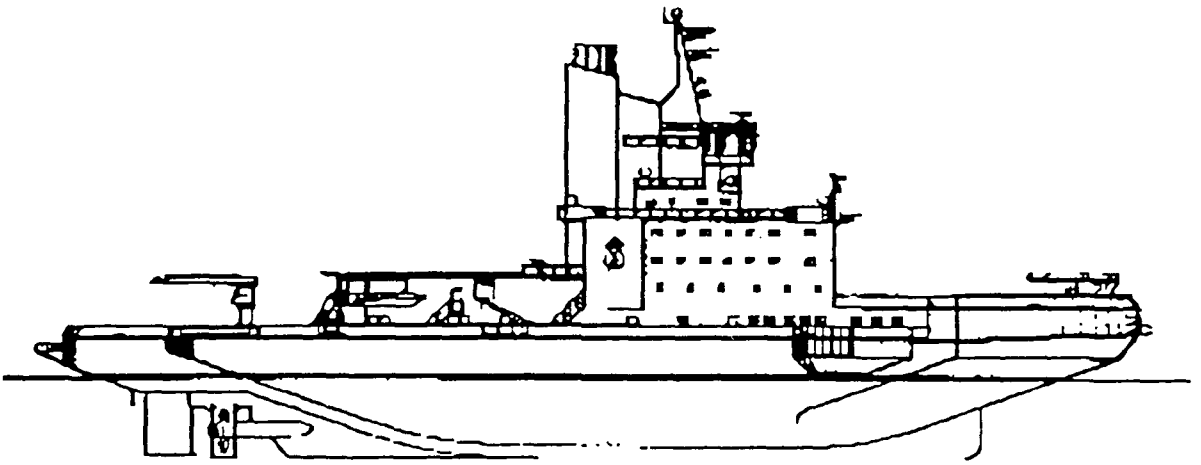
Swedish Polar Research Secretariat is a government agency under the Ministry of Education and is the focal point for Swedish polar research activities in Arctic and Antarctic regions. The Secretariat also has the responsibility for planning and organizing polar research expeditions.

SWEDARP The Swedish Antarctic Research Program with the two first expeditions to the Antarctic regions 1987/88 and 1988/89, aiming at a long term national program with expeditions every third year.

SWEDARCTIC Arctic research is currently in progress on Svalbard and Greenland. A new marine expedition to the central Arctic basin is scheduled for the early 1990, using the new Swedish arctic class icebreaker ODEN. (see picture below)

The primary goals of these expeditions are development of basic natural sciences related to climatic change in a global context and environmental research. The expeditions also provide opportunities for development and testing of technical equipment related to transportation, communication and building under arctic conditions as well as remote sensing and survey technology using Swedish space technology. The Swedish Polar Research Secretariat is mainly funding the logistics for these expeditions the research is funded through the university system.

Available funds for logistics 1987/88 - 2.0 MUSD (12 MSEK)



The picture shows the new Swedish arctic class icebreaker ODEN currently under construction at Götaverken Arendal AB shipyard in Sweden, for delivery fall 1988. ODEN will be the widest icebreaker in the world with a beam of 29.4 meters and an overall length of 105 meters. The hull is designed to resist all prevailing ice conditions in the Arctic.

4.3 Other agencies

Swedish National Board for Technical Development (STU)
STU is a central government agency providing support for technical R&D in Sweden. In addition to financial backing by way of loans, grants and scholarships, STU also provides professional services and advice. STU does not have a funding program for arctic technology, however an arctic technology project may well be launched with the help of a STU loan if it gives reasonable promise of having a possible commercial future.

Cold Region Technology Centre (COLDTECH)
COLDTECH is an organization with the aim to promote R&D regarding technology for regions with cold climate. Its founding members are the Foundation for Development of Northern Sweden, local industry and Luleå University of Technology.

Available funds 1987/88 - 0.67 MUSD (4 MSEK)

Winter Navigation Research Board (Styrelsen för Vintersjöfartsforskning)
Cooperation between The National Swedish Administration of Shipping and Navigation and The Finnish Board of Navigation to initiate and coordinate winter navigation R&D related to the Baltic Sea.

Available funds from Sweden 1987/88 - 0.075 MUSD (0.45 MSEK)

Swedish Council for Building Research (BFR)
BFR is a government agency responsible for overall planning, coordination, evaluation and funding of R&D in the building sector in Sweden

Available funds for arctic technology 1987/88 - 0.025 MUSD (0.15 MSEK)

Swedish Board for Research and Higher Education (UHÄ)
UHÄ distributes all central grants to the universities in Sweden (about 500 MUSD for research and the same amount for education). The universities then allocate the funds to their different branches.

Available funds for arctic technology (including environmental studies and natural sciences) 1987/88 - approx. 1.0 MUSD (6.0 MSEK)

5. International cooperation - an invitation.

The Swedish policy is to support international cooperation in polar research and development of arctic technology. Sweden therefore has an interest in developing working relationships with other nations and their agencies and companies active in these areas.

Potential advantages of international cooperation:

- cost sharing
- exchange of arctic experience
- business opportunities

What Sweden has to offer and others to gain:

- experience from engineering and construction in cold environment
- advanced R&D capability
- access to the Gulf of Bothnia

What other countries can offer and Sweden gain:

- operating experience in cold climates
- potentially viable markets

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ARCTIC RESEARCH PROGRAM IN FINLAND

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ABSTRACT

This paper describes both the present state and future perspectives of cold regions research and technology in Finland. To begin, the development history and technological background is briefly discussed. The current state of investments, research programs and facilities are presented in more detail. Some industrial joint research programs, which are typical for Finland, are also described. It is concluded, finally, that strategic investment on arctic offshore technology should be maintained due to future needs for northern oil and gas reserves.

1. HISTORY AND TECHNOLOGICAL BACKGROUND

1.1 Living conditions

Cold regions are considered in general as both arctic and sub-arctic areas and for the both there are several definitions. Suitable limits for the Arctic region, from a technical point of view, are given by the maximum average extension of sea ice or the extension of continuous or discontinuous permafrost on land (Fig. 1.). Sub-arctic areas are characterized in most cases by a yearly snow cover on land ard by special low temperature problems with icing, laws etc. on sea.

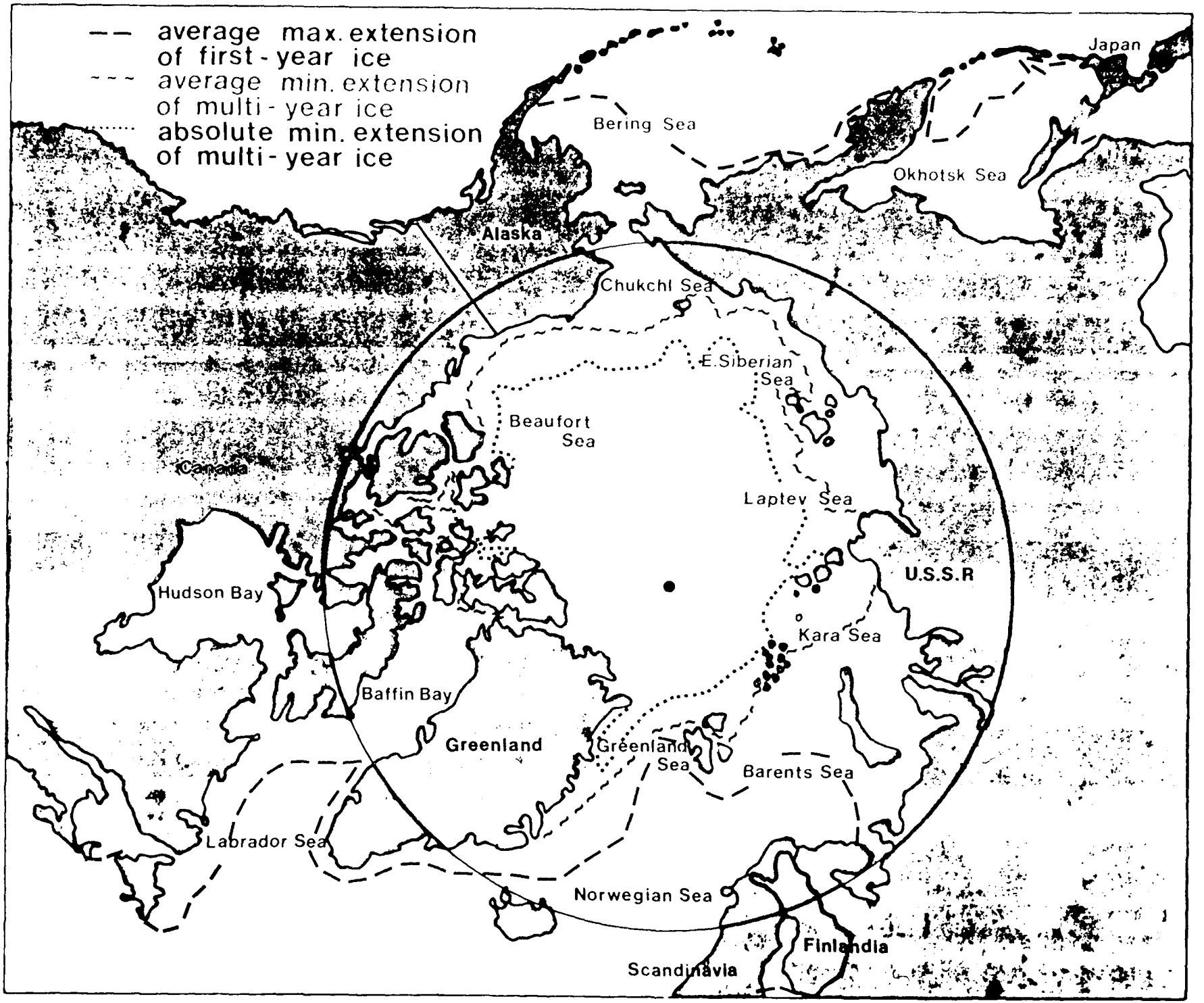

Fig. 1. Ice conditions in the arctic seas.

According to these definitions Finland mainly belongs to the sub-arctic region. Conditions similar to those in the Arctic are found in the Gulf of Bothnia and in the northernmost part of Finland (Fig. 2.). In the former area, there are difficult ice conditions with maximum ice thickness of 1 m and duration of 6 - 7 months. Ridges can reach a thickness of 10 - 20 m and extensive movements of ice are common. The northernmost part of Finland, called Lapland, has also some special areas with tundra and discontinuous permafrost.

Snow covers the whole country every winter and remains for 2 - 4 months in the Southern and 6 - 10 months in the Northern Finland. The maximum thickness of snow varies yearly from 0.5 to 1.2 m. The temperatures in summer can reach +30 ^{0}C in the whole country during some short periods. Minimum winter temperatures are normally -20 to -30 ^{0}C in the South and -40 to -50 ^{0}C in Lapland. This all means that Finland is located on the boundary of the arctic and subarctic zones and is subjected to quite cold and hostile conditions in the winter time.

1.2 Technology background

Cold regions technology has its roots in the life and customs of people in Finland and in restricted commercial activities outside the country. Nowadays the research is directed much more to supporting future technical and economic activities in arctic regions than to winter building or navigation operation in the country.

Winter navigation between Southern Finland and Sweden started as early as in 1877 by using the ice-strengthened steamship "Express". The first icebreaker for Finland was built in 1890 by a Swedish company and the first Finnish icebreaker was built not earlier than in 1939. Since then, however, Wärtsilä has built about 60 icebreakers, which is more than half of the world's icebreaker fleet. A new innovation called the "airbubbling

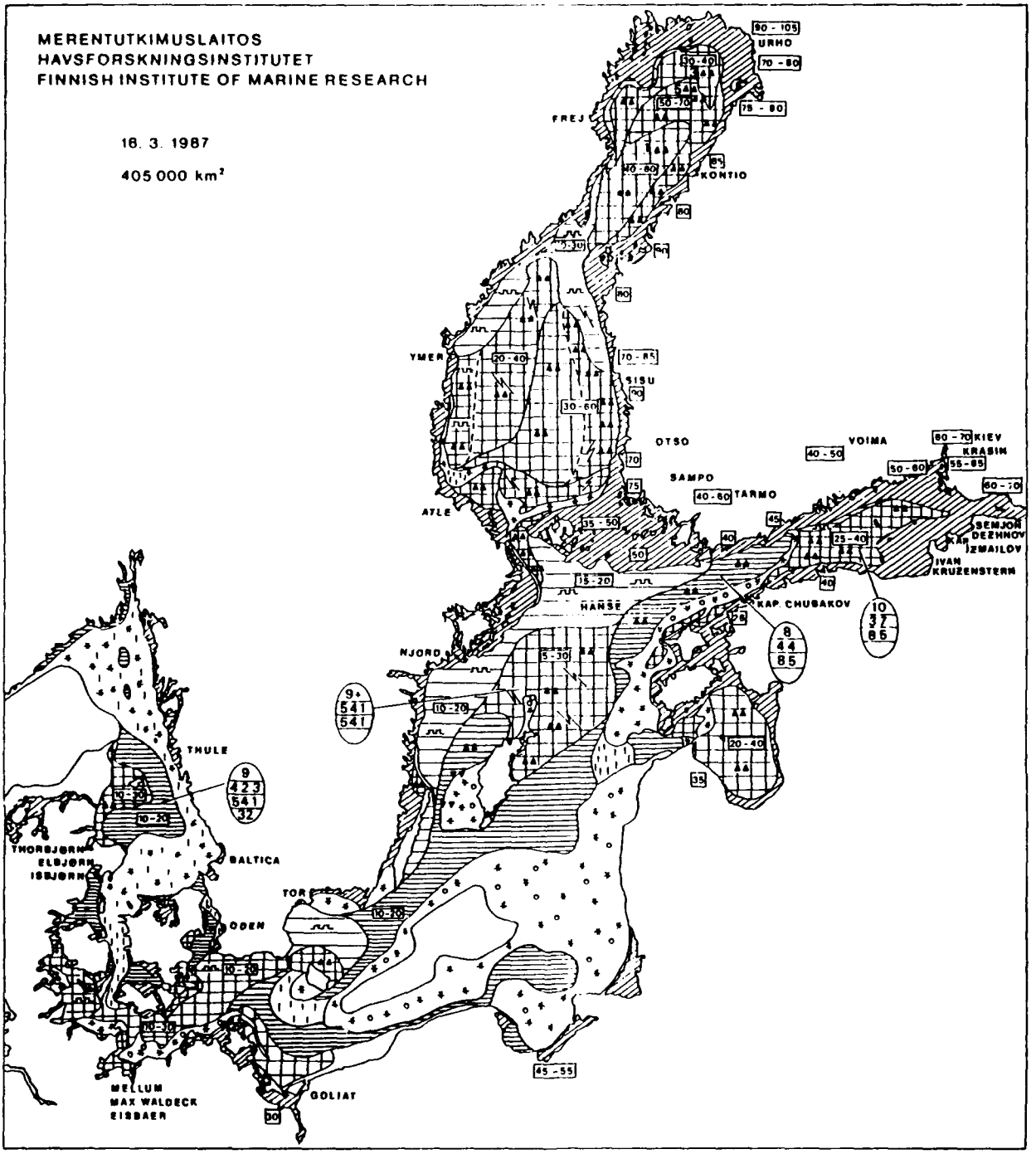

Fig. 2. Ice conditions in the Baltic Sea during a severe winter.

method", developed in the 1970's, has succesfully been applied in the last icebreakers as well as in some other types of icegoing ships. In the present situation all the important harbors in the Baltic Sea and the Gulf of Bothnia are kept open through the winter. This is done by using the 9 icebreakers of the Finnish Government.

Systematic research of icebreaking was started by Wärtsilä 20 years ago by building a special model testing laboratory. A new laboratory (WARC = Wärtsilä Arctic Research Centre) was inaugurated in 1983. Governmental research institutes (VTT, Helsinki Univ. of Technology, Univ. of Oulu) started studies of physical and mechanical properties of ice and of ice loads on structures 20 years ago as well. Problems were arising from harbor structures along the coast of Finland and lighthouses and seamarks in the Gulf of Bothnia. During the past ten years, several field research projects for testing ice breaking ships and new types of marine structures have taken place in the Gulf of Bothnia. Today, this area plays an increasing role as a natural laboratory in the Finnish ice research.
In addition to icebreakers, Finnish companies have developed and constructed during the last 20 years a variety of ice-going ship types and special vessels (research supply) which can be operated in ice. In the early 80's Rauma-Repola started to build a series of three arctic drillships. The series was completed in 1983 and there after Rauma-Repola has also built two jack-ups which can be moved or operated in mild ice conditions. These rigs have then been used for drilling on the Barents or the Okhotsk Sea.

Also the winter building has been a subject of various studies during the past 20 - 30 years in Finland. After the early 1960's, a great number of people moved in quite a short period from the country side into cities and industrial centres in the Southern and Central Finland. Following from this extensive building of houses, industrial plants, services etc. were

required. Industrialized building methods based on prefabricated systems and modules provided the means of satisfying the growing demand. After the early 1970's, year round building including special winter building methods has been developed. Large building projects carried out in the Soviet Arctic (Norilsk, Kostamus) have supported this development.

1.3 R & D Policy

Cold regions research in Finland should support to human, technical and economic activities in the own country as well as to the development of economic co-operation and trade with foreign countries. This requires continuing investment both on R & D projects and research facilities despite the decline of the arctic business today. To maintain a sufficient level of activities and investments, governmental funding has played an increasingly important role after the dramatic drop in the price of oil. Large research programs of universities and research institutes as well as industrial joint R & D projects have proved to be the Finnish way to survive. The most inportant research programs in course and facilities in use are demonstrated in the following chapters.

2. RESEARCH FACILITIES

2.1 Main Institutes

VTT (The Technical Research Centre of Finland) received at the end of the year 1986, 15 000 sq. meters of space for research, as a new research hall including an underground emergency shelter. The research hall is in Otaniemi area nearby Helsinki where most of the 34 laboratories of VTT are located. The new shelter is 22 meters below the sea level.

This new research facility has given very good possibilities also to create arctic research in Finland. In the research hall

are located one ice tank, three cold rooms where low temperatures down to -60^0 centigrades, one cold room down to -20^0 centigrades and over 500 sq. meters floor space at room temperature for heavy testing of large structures. In addition to the above mentioned new research hall, there are several cold rooms and chambers at VTT.

The Helsinki University of Technology (HTKK), which is located in the same campus area as VTT, has the largest ice tank in the world under construction. At the University, there are also several cold rooms for different kind of research.

The University of Oulu, which started the research of ice mechanics already in 1971, has a cold room where static and dynamic loadings can be simulated at temperatures down to -55^0 centigrades. A micro ice tank is used for initial testing before more comprehensive tests in some other larger testing facility.

The most famous research facility for arctic research in Finland is WARC (Wärtsilä Arctic Research Centre). The ice tank is owned by a private company Wärtsilä Marine (80 %) together with the Finnish Government (20 %). The share of governmental financing ensures that universities and other governmental research establishments can also use WARC's sophisticated research facilities.

Facilities for arctic research are here divided into three groups: cold rooms and chambers, ice tanks and in situ testing and measuring apparatus.

2.2 Cold rooms and chambers

As mentioned before, there are several cold rooms and chambers in Finland. Perhaps the most interesting one is located in the Laboratory of Structural Engineering of VTT. In this chamber test specimens can be exposed to temperatures ranging from +30^0

to -60^0 centigrades and subjected to static or dynamic load of up to ±600 kN. The walls and ceiling of the cold chamber make up a cover, which can be lifted up. So even large test specimens can be moved in. The free space of the chamber is 3.2 m x 1.6 m x 2.7 m.

In the test field of building physics the main research topics are physical performance and durability of building structures, components and materials in an arctic climate. Temperature distributions, moisture transfer, and risk of condensation as well as weather resistance can be studied under the influence of extreme temperatures down to -50^0 centigrades and temperature variations between -50^0 and +80^0 centigrades. Material tests can be performed at -70^0 up to +100^0 centigrades e.g. with 500 kN's loading apparatus which has a small box (350 mm x 450 mm x 600 mm) around the specimen.

Research of engines, fuels and lubricants is included in the activities of the Laboratory of Fuel Processing and Lubrication Technology at VTT. The Labnoratory has a cold room of 70 cubic meters with a hydraulic power unit and an engine dynamometer. The low temperature equipment is processor controlled and the minimum temperature is -60^0 centigrades. It is also equipped with a versatile data acquisition system.

2 3 Ice tanks

At the end of the year 1988 there will be three ice tanks in operation in Finland. The main data of these tanks are given in the following table.

DESCRIPTION		WARC	VTT	HTKK
Constructed		1983	1988	1988
Length	(m)	60.0	15.0	40.0
Width	(m)	6.5	3.2	40.0
Depth	(m)	2.3	1.4	3.0
Max. speed	(m/s)	3.0	0.5	3.0
Ice type		own	EGAD	EGAD

VTT is going to use its ice tank mainly to study ice-structure interaction behaviour. Ship model testing is out of the research scope. VTT's ice tank is small but has many advantages like low operation costs (less than 1000 USD per day), only few people needed to operate the tank, flexibility in carrying out various kinds of tests and less time required to prepare the ice sheet.

Because there are several unused ice tanks in the world today, VTT's ice tank is planned to be some kind of a multipurpose ice testing facility. The tank room offers a large space cold room (down to -30^0 centigrades) while the tank itself is covered by a deck. It is then possible to carry out various kinds of research in the tank itself: adhesion and friction measurements between ice and different materials, spray-ice research, determination of strength parameters of different ice formations, the behaviour of oil in ice covered water etc.

The general layout of the new ice model basin at the HTKK is shown in the Fig. 3. Originally it was an ordinary clear manoeuvring and seakeeping basin of the Ship Laboratory which was completed in 1970. The work to convert it to an ice model test has started and the basin will be ready in 1988.

These two new ice tanks have as 'a big brother' the ice model basin of Wärtsilä Marine, WARC. Perhaps 85 % of WARC's research has been ship model testing but lately the share of model testing of offshore structures in ice has increased. For these tests WARC has also developed its own fine grained model ice.

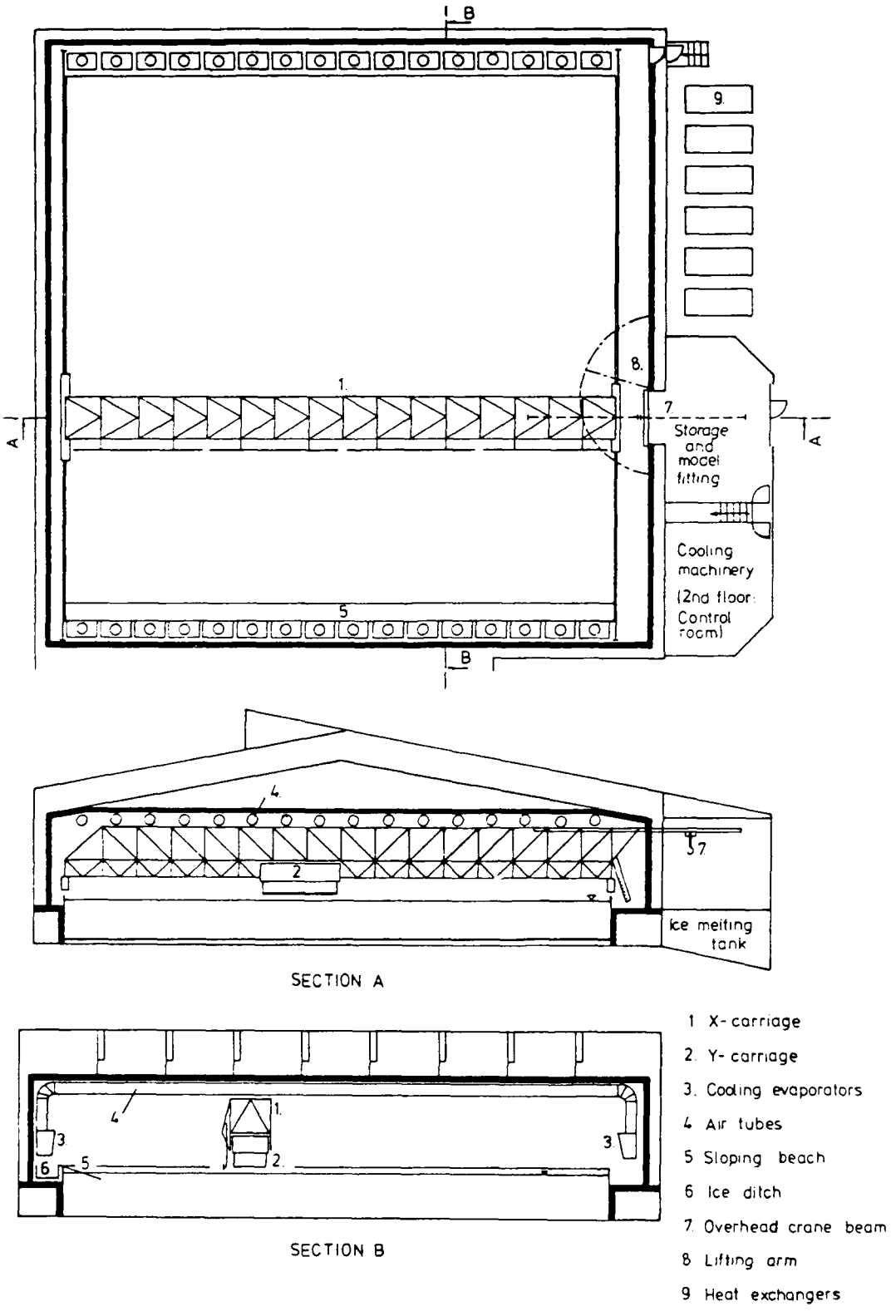

Fig. 3. General arrangement of the new basin of TKK.

2.4 Total investment on research facilities

The exact number of total investments on arctic research facilities in Finland is difficult to give. The two new ice tanks will probably cost altogether about 5 million USD before they are in operation. Annual costs to operate all these three tanks in Finland will be about 3 Million USD.

There are altogether about 50 research scientists solely devoted to ice related research at WARC, VTT, universities and other research establishments. If we take into account all kinds of arctic research, the number of scientists must be multiplied by four.

3. VTT'S ARCTIC RESEARCH PROGRAM

VTT started systematic arctic technology research only about 10 years ago. The activity has increased very rapidly thereafter and today about 100 man years of R & D work will be performed in joint projects between more than ten laboratories.

The main subjects of arctic research are as follows:

* Ship technology
  - Strength of arctic ships
  - Full-scale measurements of ships in ice

* Offshore technology
  - Ice loads on structures
  - Small scale model tests

* Building technology
  - Construction on permafrost
  - Modular construction systems
  - Concrete technology in cold climate

* Materials technology
  - Fracture of metals at low temperatures
  - Welding at low temperatures
  - Textile engineering

* Automation and measurement engineering
  - Research and measuring equipment
  - Data-acquisition systems
  - Design of microprosessor based systems

* Machine engineering
  - Hydraulics and tribology
  - Work safety

* Environmental problems in cold regions

During the years 1983 - 1986 VTT made special effort to create arctic technology research. This research program consisted of 13 projects. Total volume of the program was 33 man years and the costs about 2.5 Million USD. The following list of topics includes also other projects than those belonging to the research program mentioned. Some of the projects have already been completed. But, anyhow, the list will give a good picture of VTT's arctic research.

NAVIGATION IN ARCTIC SEAS

Calculation models of ice loads	Reliability of arctic vessels
Ice loads on propeller blade	Assesment of ice damage in the Baltic
Updating of Finnish - Swedish ice class rules	

OFFSHORE STRUCTURES AND MATERIALS

Structural and materials technology in arctic conditions

Strength of structures at low temperatures

Ice stress and strain measurements adjacent to offshore structures

Sea bottom scouring around offshore structures

Arctic concrete technology

New testing procedures for arctic materials technology

Adhesion strength of ice

Selection principles and construction technology of artificial islands

Determination of ice loads by model tests

Ice accretion on marine structures

Wave loads on gravity platforms

Fracture properties of welded structural steels in arctic use

Full scale measurements of ice forces against lighthouses

Dynamic interaction between offshore structures and ice fields

ARCTIC CONSTRUCTION

Fundamentals of material, work and construction technology of arctic offshore structures

Construction of traffic routes and foundations of houses on permafrost

Geotechnical properties of frozen soils and frost susceptibility	Use of blast-furnace slag in earth and road construction
Long-term performance of thermal insulation materials in road structure conditions	Influence of weather and maintenance on road surface in winter
Physical properties of snow	Frost heave
Thermal design of earth structures	Experimental road construction in arctic conditions
Ice loads on structures	

INTRUMENTATION AND MEASURING SYSTEMS

Measurement of snow and ice properties using IR - techniques	Automatic data logging system for arctic environments
Measurement systems for arctic vessels	Long-term measurements of ice loads and ice-induced stresses
Long-term measurement of ice loads on propulsion machinery and ice resistance	

MISCELLANEOUS

Oil hydraulics in arctic conditions	Seals and bearings in arctic machines

Power transmissions in arctic environment	Reliability improvement of hydraulic circuits
Extra costs due to winter conditions in goods transport	Heat and moisture transmission through winter work wear
Construction of a sweating thermal mankin	

4. ARCTIC OFFSHORE TECHNOLOGY PROGRAM BY TEKES

4.1 Research Policy of TEKES

Technology Development Centre (TEKES), Finland, coordinates and finances "Arctic Offshore Technology" program aiming to promote the basic knowlegde for industrial utilization in arctic offshore technologies.

TEKES is a government agency founded in 1983 aiming to raise the level of Finnish technology and to improve the international competitiveness of Finnish industry.

To achieve this TEKES:

- plans, coordinates, and finances national technology programmes,
- promotes technology transfer and supports international cooperation,
- plans and realizes national technology policies,
- finances technology promoting projects in research institutes and companies,
- consults small and medium sized -companies in their development work.

TEKES annual budget exceeds 100 Mill. USD and its personnel is about 100.

Technology programmes by TEKES:

Technology program- phenomenon is an important part of todays Finnish technology policy. In technology programmes TEKES aims to create relatively comprehensive basic know how bases in certain new key technlogy areas. Programmes are planned in close cooperation with industry and research institutes but mainly operated in research environment. Now there are around fifteen active programmes - each three to four years time span and of total 2 - 25 Mill. USD each. So the total technology program volume is roughly 25 Mill. USD annually. One of these programmes is arctic offshore technology program.

4.2 Arctic offshore technology program

Arctic offshore technology program aims to raise the technology know how basis by focusing applied R & D-activity to certain key areas of Finnish industry. The program includes applied research and some even basic research parts, but it aims clearly to industrial utilization.

The program has been planned in cooperation by TEKES, industry and research institutes. It is a five years program (1985-89), and its financial volume is totally about 5 Mill. USD. The main funding comes from TEKES (about 80 %). Other financiers are research carrying institutes and the industry. The program does not include direct product development work, which is carried in companies.

The main organisations involved in research work are Technical Research Centre of Finland (VTT)/Ship laboratory and Laboratory of Structural Engineering, University of Oulu, Helsinki University of Technology and companies (shipbuilding, building and construction).

The main research areas of the program are:

- interaction between ice and structures ("ice management")
- materials technology in arctic environment
- support activities

The first part "interaction between ice and structure" is the largest one and it includes the following joint projects or project groups:

- interaction between ice and ship,
- ice technology for deep water platforms,
- stress state in an ice field,
- ice loads on ship fairway signs,
- ice loads in caisson type structure (semi full scale),
- forces generated by ice crushing in large contact areas,
- mathematical modelling of the stress-strain relation of ice,
- components of resistance encountered by a vessel advancing in level ice,
- improvement of ice model scale measurements of offshore structures.

The second part "materials technology" includes projects:

- special concrete technologies in arctic offshore structures,
- adhesion of ice on structures,
- high strength steels in arctic structures.

The third part "support activity" includes:

- databank for arctic technology
- arctic logistics.

Arctic technologies in offshore as well as in other environments are an important key area for Finnish industry and for Finlands future. The sub-arctic location with cold and long winter

together with Finlands highly developed industrial, educational and technological infrastructure give a good starting "platform" for this.

5. INDUSTRIAL JOINT PROGRAMS

In arctic R & D programs by VTT, TEKES or other governmental organizations, the share of public financing is more than 50 %, sometimes up to 100 %. Research institutes will take in this case also the main responsibility for a project. Nevertheless, private companies or industrial organizations participate in the most of projects and also finance the missing share of funding.

Another type of R & D project, typical in Finland, is so-called "Industrial joint project". It is jointly financed by two or more private companies or industrial organizations, which then take the advantage of sharing high R & D costs. Such a project can often get also some public financing, especially from the product development fund of TEKES. However, the share of public money is in this case less than 50 %. Services of universities or research institutes are normally used also by these types of projects.

On the field of arctic navigation and offshore technology there are a couple of industrial joint projects of this type which will be shortly discussed in the following.

In the so-called "Test Cone Project", a hybrid cone structure has been installed around a concrete lighthouse on the Gulf of Bothnia. The purpose was to study ice loads upon the cone and ice behavior around it in a very large scale (1 to 2) to find out design loads for fixed arctic drilling platforms. The cone has now served succesfully three winters and some preliminary results have allready been published in the connection of arctic offshore conferences. Final costs of the project will increase

to 1 mill. USD and will be shared by several private companies (Rauma-Repola, Wärtsilä Marine, Rautaruukki etc.) and TEKES. Operational responsibility for the ice research has been taken by the University of Oulu.

A second project of interest deals with the construction of a "Research Icebreaker" for Finland. In the late of 1986, the decision was made to convert the icebreaker Sampo (9000 hp, constructed in 1961) to an icebreaking research vessel. The City of Kemi bought the vessel in 1987 and formed a holding company to operete it. Furthermore, Wärtsilä Marine, VTT, Helsinki University of Technology and the University of Oulu established a "Research Consortium" to use Sampo for ice breaking research and ice behaviour studies in the Gulf of Bothnia. In addition to ice research, the ship will be used for ice breaking tourist trips outside the research season.

The conversion work of Sampo has been recently completed by Wärtsilä Marine and first test trials will be carried out during this winter. The operation costs of the vessel will roughly increase to 250 000 USD per winter. Additional costs of research work and facilities will be financed on project by project basis.

6. CONCLUSIONS

Finland has a history and traditions of about 100 years in arctic navigation. Ice breakers and ice-going ships have been key products for finnish companies in the worldwide arctic business. Since the late of 70's, appreciable efforts have been made to penetrate also into arctic offshore technology. Finnish companies have manufactured e.g. arctic drilling rigs, arctic supply vessels, drilling equipment etc.

Despite of the decline in the offshore industry and arctic activities, especially, both Finnish companies and institutions

have decided to maintain the level of investments on arctic offshore. Research programs of governmental institutes and joint research programs of companies and industrial organizations will play an important role in this strategy.

Investments on new research facilities within the next two-three years will be on the level of 7 - 8 mill. USD. Operational costs of ice tanks and costs of research projects will together be about 5 mill. USD per year. In addition the Government of Finland has ordered (for the Institute of Marine Science) a new antarctic research ship on the price of about 15 mill. USD. The sums presented before do not include product development costs of private companies.

The arctic offshore and ice related research staff in laboratories of WARC, VTT and universities is about 50. Including basic reseach on the field arctic marine science and research in private companies, the total arctic research staff in Finland is propably between 200 - 250 people.

R&D IN ARCTIC TECHNOLOGY: A NORWEGIAN OUTLOOK

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Looking on a map of the world, one will surely appreciate Norway's interests in arctic and cold clima technology. For several centuries, Norwegians have explored the arctic areas, starting with fishing and hunting, later mining and mineral exploration and in the recent years, searching for petroleum resources onshore and offshore.

Today, the area of main interests regarding development of an arctic technology, is shown on figure 1. As exploration for oil and gas resources is the primary driving force in this development, figure 1 also displays the area of interest regarding future petroleum exploration activities.

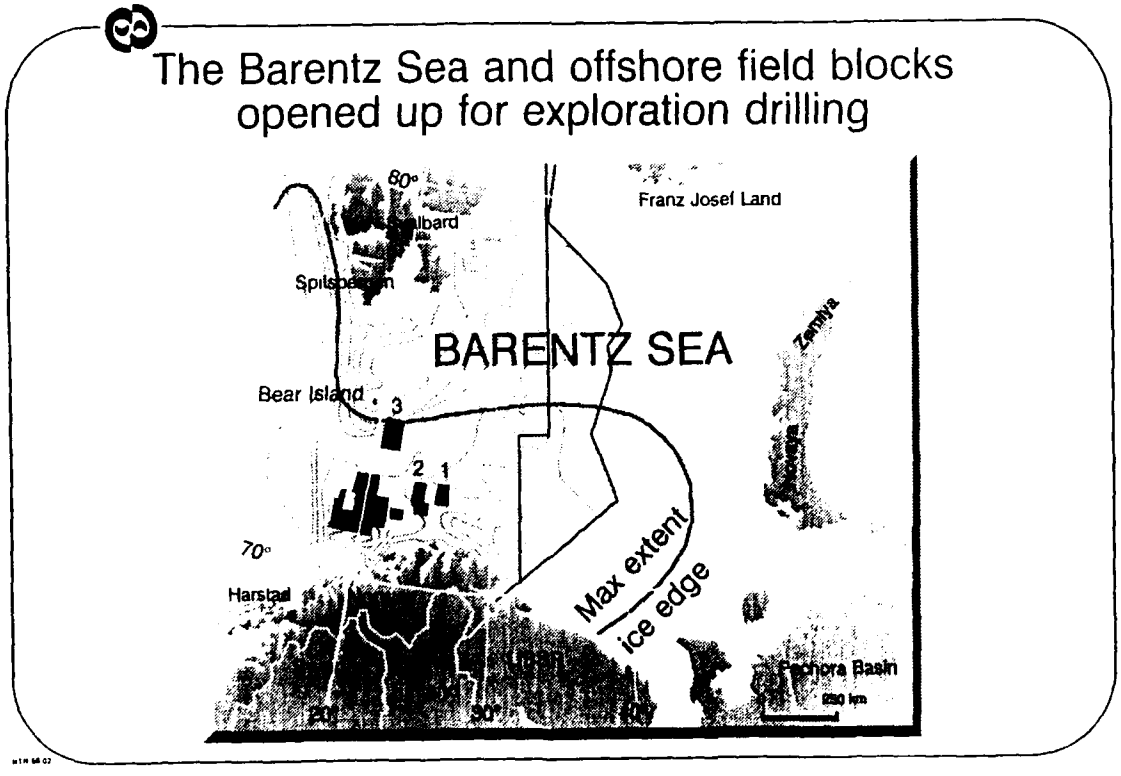

FIGURE 1

To evaluate the impacts and priorities of arctic research in Norway, some basic conditions will prevail:

- Parts of the area onshore (the Svalbard archipelago) are governed by the Svalbard Treaty whereby administration of Svalbard is undertaken by Norway. Norwegian legislation and jurisdiction will in general be valid.

- Having a total responsibility of the activities on Svalbard and the surrounding waters, the impact and effects of any industrial activities in the arctic must be adressed to, e.g. pollution and environmental control, protection of wildlife and fisheries e.g.

- Both the mainland of Svalbard and the Barentz sea are promising areas for future findings of petroleum resources, but profitable resources are yet to be found.

During the periode 1983-1986, the yearly funding of R&D in arctic technology has developed as shown on figure 2. Looking more in detail, the substantial increase in funding during 1984 is mainly a result of large R&D programs launched by the oil companies under the Technical Agreements with the Norwegian Government. As great yearly variations occur, it is difficult to maintain a constant level of R&D work, and public funding can in no way compensate for the withdrawal of private funding.

In public funding of R&D work in arctic technology, the Royal Norwegian Council for Scientific and Industrial Research, or

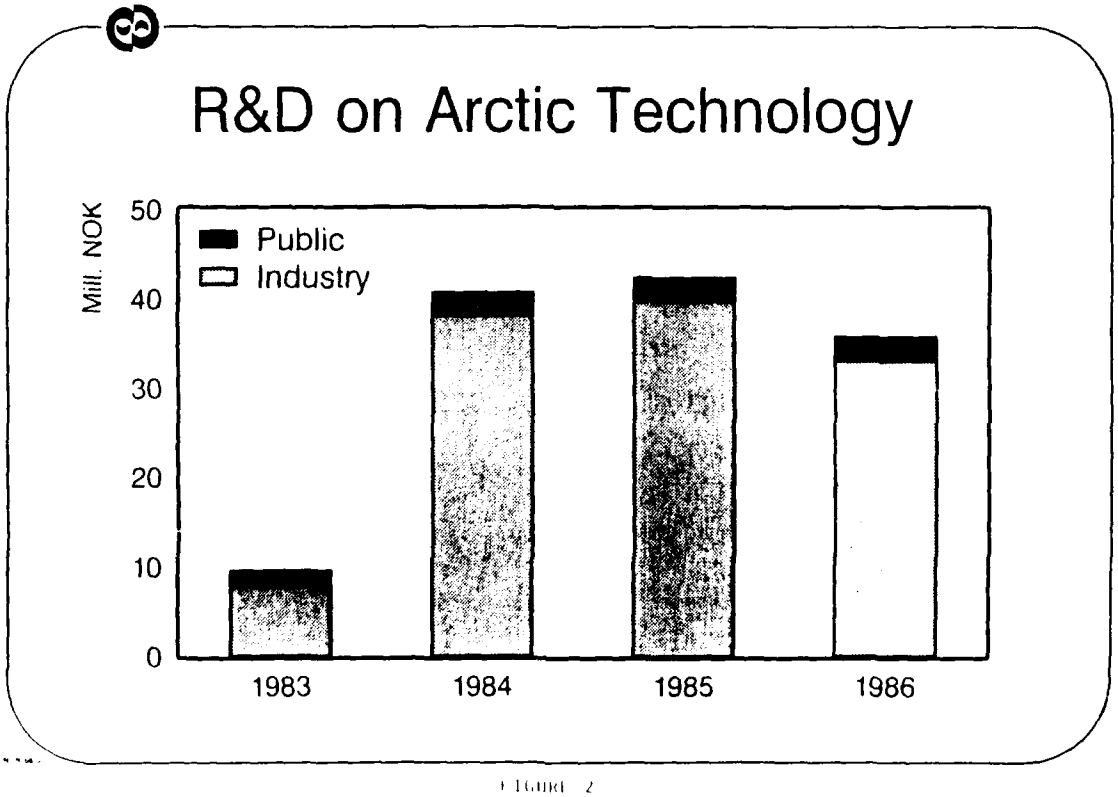

FIGURE 2

abbreviated NTNF in Norwegian, plays a key role. As public funding is at present about 2,5 mill NOK a year (or about 400 000 $), only a limited number of projects can be financed by public sources. Simplified calculation methods for ice strength calculations, subsea instrument for ice tracking and icing sensor are some of the ongoing projects in this category. The projects are scattered and depending on promising product ideas, and are not part of any more comprehensive R&D programs.

The major part of the financing by the industry on figure 2, is contributed to the oil companies, only a marginal part are financed by private industry otherwise. In this context, the oil companies are (at present) 3 Norwegian and 8 international oil companies appointed as operators north of the 62° N parallel.

Partly the resources are pooled in OKN (Committee of Operators in Northern Waters), partly the oil companies launch single client projects with Norwegian research institutes and manufacturing industry.

In general, R&D programs financed by OKN are open research projects, to provide a basis for subsequent development of constructions, methods, systems, equipment for arctic or sub-arctic waters. The major programs financed by OKN are:

1. ODAP - "Ocean Data Acquisition Project"

   Major activities is measurements of waves and sea currents and tidal measurements. Starting in 1980 the program will tail off in 1987.The accumulaied costs for the ODAP-program is 80 mill NOK plus, and the area covered by the program is north of the 62° N parallel.

2. Surveillance of earthquake activity.

   The 3-year program starting in 1985, costs abt. 7 mill NOK.

3. MOMO - "Metheorological Ocean Modelling Project"

   The project goal is to develop a computer model of sea behaviour. Starting with compiling and synthesizing of available data and methods, the next step will be to generate a computer model of ocean currents.

4. IDAP - "Ice Data Acquisition and Analysis Project"

   Program objectives are to map and analyse the ice front and drifting ice over some years, using vessel, satellite and air borne tracking sensors.

Total costs for these programs in 1988 will be about 21 mill NOK.

R&D programs financed by OKN during the recent years include studies of plough marks, offshore icing and low pressures in arctic areas.

During the 1980's, the oil companies have taken a more active part in program definitions. Today, most of the research work is contracted to R&D institutes on commercial terms. Although OKN program plans extends over several years, R&D commitments are made year by year only.

As can be seen from the previous, the research work financed by OKN relates to mapping of oceanic, metheorologic and ice data. The data could otherwise have been provided by public financed programs and services as normally done. If and when exploration drilling and field development in the arctic and sub-arctic area take place, dependable environmental data acquired over several years will be a prerequisite for technical development. The oil companies therefore have found it necessary to launch R&D programs as shown by themselves.

Subsequent to the programs financed by OKN, some of the oil companies have launched programs for development of technology for arctic and sub-arctic conditions. ESSO Norway has together with SINTEF started the ESARC (ESSO/SINTEF Arctic Research Program). SINTEF, the Foundation for Scientific and Industrial Research at the Norwegian Institute of Technology, is located in Trondheim. Among others, SINTEF include the major R&D institute on arctic technology in Norway, and will also contribute financially to minor parts of the ESARC-program.

The ESARC-program objectives are:

* Identify representative development scenarios for selected sites in the study area

    - Develop task schedule of activities needed for exploration, production, and transportation from each representative site.

    - Describe equipment, structures, and vessels associated with each phase of the development.

    - Estimate total development cost based on cost estimates of each major component.

* Define environmental data collection programs needed to support early planning and evaluation stages of a development.

* Recommend technology development programs for any new or improved technology which is included in development scenarios.

Included in the ESARC program are the building of an ice testing laboratory at SINTEF, Trondheim (inaugurated January 1988) and the design and specification of a closed-loop cold wind tunnel with sea spray nozzles.

Partly the ESARC program overlaps multi client programs financed by OKN. The total activity of the ESARC program is 30 mill NOK over a 3 years periode starting August 1986.

Other R&D work concerning arctic technology and mainly financed by the oil companies are devoted to methods and equipment for deicing, weather sensors, detectors for drifting ice e.g. In general there is a

reluctant attitude to start arctic technology development programs until required by planned industrial activities in the areas.

In the presentation, a limit definition of "arctic technology" has been used. A petroleum industry, either on- or offshore, may have a detrimental impact on the environment. Jointly sponsored by the Government and by the oil companies, programs and projects have been undertaken in areas like:

* environmental control and pollution combattment
* protection of wild life and fisheries
* effects of oil spills in icy waters
* safety and preparednes under arctic conditions
* working environment in arctic regions

As the international oil companies are heavily involved in the R&D work, a transfer and jointly build-up of arctic technology with other countries takes place. Bilateral and multilateral R&D agreements are also instrumental in this context. Icing on offshore constructions, design criteria for arctic structures and remote sensing of ice conditions by satellite are some of the projects under bilateral agreements between Norway and Germany, France and Canada respectively. Some research on cold clima technology is ongoing between universities in Northern Norway, Sweden and Finland at present.

To summarise the presentation, some trends with bearing into future arctic R&D in Norway shall be sketched.

For various reasons, there is a greater understanding by the Government to support arctic R&D in Norway. A committee to issue a "White Paper" on the matter was recently established. Concessions for exploration drilling in the northern waters will be granted, which requires new technology or "winterization" of present technology to take place.

To compensate for the decline in coal mining at Svalbard, other industrial activities are looked for. Aquaculture, mineral exploration, polar research as an industri in itself,or controlled tourism are some of the ideas launched in this respect.

The shipping and marine operation industry in Norway have presented plans for a more extensive research program on floating structures in arctic waters. When exploration drilling in the area commence, marine and logistic services must be solved in a reliable and economic way.

But the main push to technology development in the arctic areas, will depend on recoverable petroleum or mineral resources to be found.

U.S. FEDERAL ARCTIC RESEARCH

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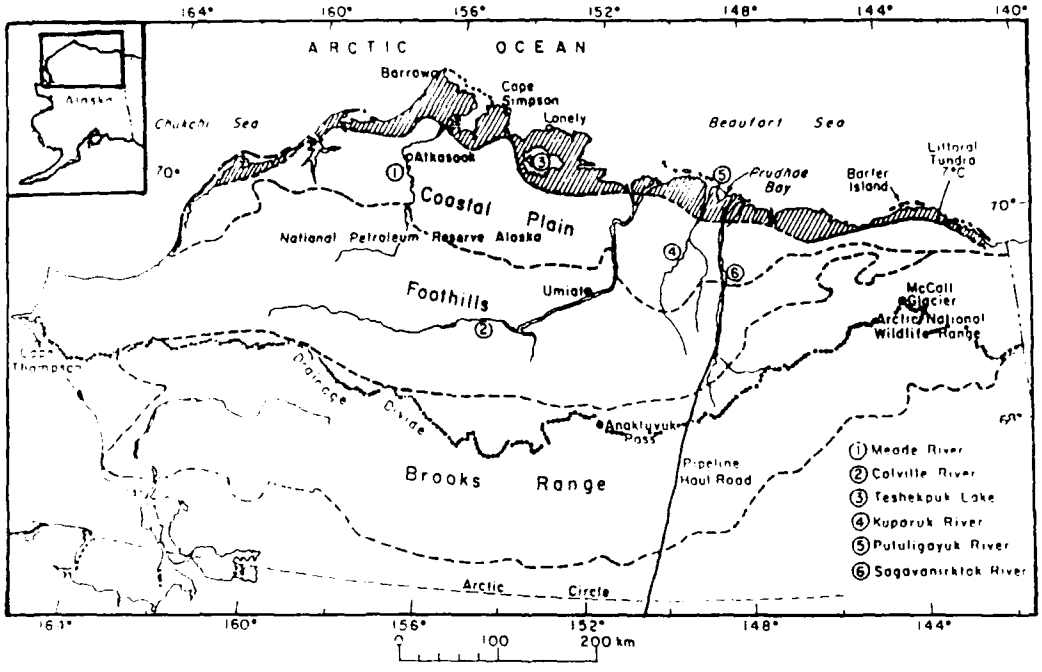
The United States is an arctic nation, possessing more territory above the Arctic Circle than Norway, Sweden or Finland. Thousands of Americans work and live in the Arctic, and the U.S. has substantial natural resources and important strategic interests there. Yet, before the discovery and development of the petroleum reserves in northern Alaska, much of the U.S. Arctic was largely ignored. To redress this long-standing neglect, Congress passed in 1984 the historically important Public Law 98-373, entitled the Arctic Research and Policy Act.

The purposes of the Arctic Research and Policy Act of 1984 were to establish national policy, priorities and goals, and to provide a plan for basic and applied scientific research with respect to the Arctic. To these ends, this legislation has been highly successful, as is evident from the following results:

- The U.S. now has an Arctic Research Policy Committee to define overall policy and coordinate Federal research efforts.
- The U.S. now has an Arctic Research Commission that meets regularly to advise the President and Congress on arctic research.
- The U.S. has a comprehensive Arctic Research Plan, which was sent to the President and Congress in July 1987.



The Alaskan Arctic. Shown are the physiographic provinces and the littoral zone (hatched area), with a July mean temperature of less than 7°C.

- The U.S. is now looking closely at the need for new research efforts to benefit residents of the Arctic and the Nation as a whole.

These accomplishments are the result of the cooperation among member agencies of the Interagency Arctic Research Policy Committee and the Arctic Research Commission, both authorized under the Act and established by President Reagan in Executive Order 12501 of January 28, 1985. The participation in the planning review process by the government of the State of Alaska, residents of the Arctic, the private sector and public interest groups has resulted in an Arctic Research Plan with strong technical and functional value. This planning process has created new opportunities for arctic research, as well as for the application of existing knowledge to economic, societal, security, and environmental challenges facing the U.S. in the Arctic.

THE INTERAGENCY ARCTIC RESEARCH POLICY COMMITTEE

The Interagency Arctic Research Policy Committee, which met initially in December 1984, consists of representatives of the National Science Foundation, Department of Commerce, Department of Defense, Department of Energy, Department of Health and Human Services, Department of Interior, Department of State, Department of Transportation, Environmental Protection Agency, National Aeronautics and Space Administration, Smithsonian Institution, Office of Management and Budget and Office of Science and Technology Policy. At its initial meeting, the Interagency Arctic Research Policy Committee adopted the following policy. Arctic research was stipulated to be aimed at resolving scientific and technological problems concerning the physical and biological components

of the Arctic and the interactive processes that govern the behavior of these components. These objectives included increasing knowledge of such issues as use of the Arctic as a natural laboratory, national defense, natural hazards, monitoring of global climate and weather, recovery of energy and minerals, transportation, communications, renewable resources, pollution, environmental protection, health and the adaptation of Native cultures to social and economic change.

The Arctic Research and Policy Act require that the Director of the National Science Foundation ensure that the requirements of the Act pertaining to the Interagency Committee are fulfilled. Furthermore, the Act and Executive Order require that NSF be responsible to implementing arctic research policy.

Among the Interagency Committee's assigned responsibilities are the following:

- Survey arctic research conducted by Federal, State and local agencies, universities, and other public and private institutions.
- Work with the Arctic Research Commission to develop and establish an integrated national arctic research policy.
- Develop a five-year plan to implement the national policy.
- Consult with the Commission on development of the plan, and existing and future research programs.
- Provide the necessary coordination, data, and assistance for the preparation of a single integrated, coherent multiagency budget request for arctic research.
- Facilitate cooperation among Federal, State and local governments in arctic research, and recommend the undertaking of neglected areas of research.
- Coordinate and promote cooperative arctic research programs with other nations.
- Promote Federal interagency coordination of all arctic research activities, including logistical planning and coordination and the sharing of data and information associated with arctic research.

THE ARCTIC RESEARCH COMMISSION

The Arctic Research Commission consists of three members selected from academic or research institutions, one from industry, one from the indigenous residents of the U.S. Arctic, and the Director of the NSF. In providing representation of these various constituencies on the Commission, the intent was to ensure that it would give attention to national needs and those of State and local governments, to scientific questions and practical problems, and to short-term objectives and the longer-term needs required by the Nation.

Among the Commission's assigned responsibilities are the following:

- Develop an integrated national arctic research policy.

Trans-Alaska pipeline and haul road.

- Cooperate with the Interagency Arctic Research Policy Committee in establishing a national arctic research program plan to implement the policy, and advise and assist the Interagency Committee as needed.

- Foster cooperation among Federal, State and local governments in regard to arctic research, and work with the Governor or Alaska and State organizations in formulating arctic policy.

- Review Federal agency research programs in the Arctic to improve coordination, and review the annual budget request for arctic research in relation to the goals of the five-year research plan.

- Recommend ways to improve logistical planning and support for arctic research.

- Suggest methods for improving efficient sharing and dissemination of data and information on the Arctic.

The Commission has no power other than that of persuasion and does not provide funds for research. It does, however, as stipulated in the Act, report to the President and to the Congress by January 31 of each year on its activities during the previous fiscal year, as well as at other times when particular issues arise.

The original members of the Arctic Research Commission were appointed on February 28, 1985 and the Commission began its work shortly thereafter. Throughout its deliberations on arctic research policy, the Commission has considered research needs and ways to arrive at setting priorities. The adopted approach has been to view the Arctic as a large-scale natural system made up of strongly interacting components. Understanding the processes and interrelationships within the system provides the key to solution of problems such as those related to resource development, environmental protection and health, as well as to broader problems of climate, air pollution and marine and terrestrial ecosystems.

From its inception, the Commission has continued its close cooperation and interaction with the Interagency Committee. For example, to provide guidelines for the development of the Five-Year Arctic Research Plan, the Commission prepared the report, *National Needs and Arctic Research: A Framework for Action*. In addition, the Commission prepared an analysis of the preliminary draft of the five-year plan and subsequently attended the workshop held by the Interagency Committee in November 1986 to assist in the refinement and further development of the Plan. The Commission reviewed the interim final draft plan at its meeting on March 5-6, 1987 and subsequently endorsed it.

THE ARCTIC RESEARCH PLAN

The Arctic Research Plan, finalized in 1987, presents a detailed description of arctic research needs from 1987–92. It divides research priorities into three broad areas: *Atmosphere and Oceans, Land—Its Resources and Environmental Interactions*, and *People*. The plan is a comprehensive statement of national needs and priorities in the areas of national security, resource development, and acquisition of new scientific knowledge of the Arctic. As stated above, the Plan was reviewed not only by the Arctic Research Commission, but also by the Governor of Alaska, residents of the Arctic, the private sector, and public interest groups.

Major sections of the 350-page plan are *Upper Atmosphere and Near-Earth Physics, Ice Dynamics, Weather and Climate, Marine Ecosystems, Land Resources, Land-Atmosphere Interactions, Coastal Processes, Engineering, Health*, and *Social Science*.

Generally, each section first briefly describes the current state of knowledge, lists major research priorities, and makes recommendations of how to accomplish this research. Of course, the plan will be updated periodically, as each five-year period draws to a close.

ARCTIC RESEARCH ACTIVITIES

U.S. government research is being conducted under the auspices of all the agencies on the Interagency Committee. In fiscal year 1988 the breakdown of the research was roughly as follows: Department of Defense—24%, Department of Interior—24%, National Science Foundation—24%, NASA—17%, Department of Commerce—5%, Department of Energy—3%, Department of Health and Human Services—1%, Smithsonian Institution—1/2%, Department of Transportation—1/2%, and the Department of Agriculture—1%. We will now briefly describe some of the arctic research activities of these agencies.

Department of Defense

Arctic research for the Department of Defense is conducted by all three military services and includes virtually all environmental sciences, engineering, and health disciplines. A total of $23.9 million was devoted to research and related testing in FY 1988. The primary study areas (in order of their FY88 expenditures) are oceanography; snow, ice and hydrologic research; upper atmosphere research; arctic engineering; medical and human engineering; lower atmosphere research; and geologic and frozen ground research.

The arctic research program of the Department of Defense is designed to develop the knowledge, understanding and capability to conduct military operations in the Arctic as the defense needs of the nation require. The scope of current research ranges from human performance in arctic environments, to oceanography, to atmospheric and ionospheric research at high latitudes.

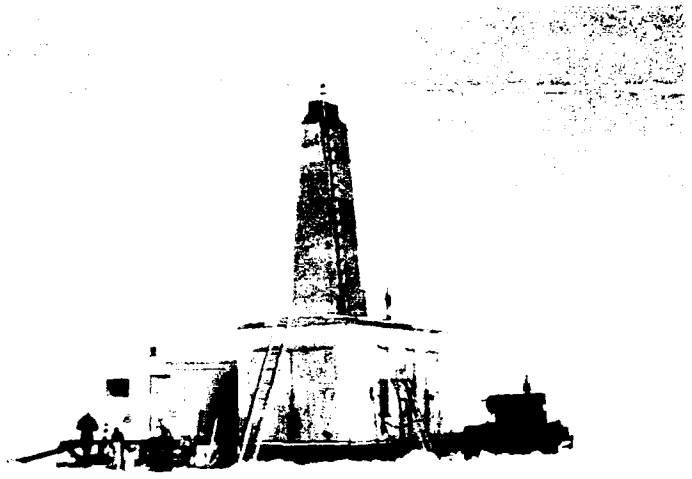
Because of their specific missions, the different armed services have different research goals. The Army is strongly driven by requirements to understand the character and behavior of arctic terrain, cold-weather human performance and arctic engineering. The Navy's arctic interest is obviously oceanographic, but it also includes low-level weather conditions over polar ice and their impact of ice behavior and naval operations. The Air Force's primary interest in the Arctic is the impact of ionospheric processes on communications, navigation and surveillance systems.

Department of Interior

The Department of Interior conducts research, mapping and monitoring programs throughout Alaska and its offshore regions and manages lands established under the Alaska National Interest Lands Conservation Act. These activities are performed by six services or bureaus, each with administrative and technical offices located in Alaska. In FY 87, a total of $24 million was identified in support of these activities and $23.8 million was expended in FY 88. Five major agencies are administered by the Department of Interior: the Minerals Management Service, the U.S. Geological Survey, the Fish and Wildlife Service, the Bureau of Land Management, the National Park Service, and the Bureau of Mines.

Arctic research by the Minerals Management Service is conducted under two major programs: the Technology Assessment and Research Program, and the Alaska Environmental Studies Program. The TA&R Program is responsible for (1) assessing and evaluating technology, equipment, industry procedures and internal procedures relevant to the post-lease exploration, development and production of minerals on the Outer Continental Shelf, (2) applying engineering and research approaches to mitigate identified hazardous conditions, and (3) transferring the resulting information to Minerals Management Service personnel. The Alaska Environmental Studies Program conducts research in such areas as protecting endangered species, protecting marine mammals and fisheries, monitoring the long-term effects of oil and gas discharges, modeling pollutant transport, and conducting sociological studies of the effects of development on arctic communities.

The U.S. Geological Survey conducts both terrestrial and marine research in the Arctic in a number of disciplines. Among these are research on energy and mineral location and assessment, mitigation of natural hazards, investigation of the effect of sea ice extent on climate, understanding the behavior of glaciers, and obtaining information about the Earth's crust and upper mantle to understand the occurrence of mineral resources and geologic hazards (such as earthquakes and volcanic eruptions).



Coring drill setup on Beaufort Sea ice cover.

The Fish and Wildlife Service addresses a variety of arctic and subarctic problems with research involving such topics as protection of fisheries, land and sea mammals and waterfowl, and the development of new methodologies to study the population and habitats of fish and wildlife. Much of this research is focused on minimizing the impact of resource development in the National Wildlife Refuges in Alaska.

The Bureau of Land Management's arctic research program consists primarily of inventory, monitoring and applied research activities focused on energy, minerals and renewable resources. These activities are conducted over 32 million acres of surface and subsurface lands and are performed entirely in terrestrial and freshwater environments.

The National Park Service conducts research in all the areas it manages in arctic Alaska (together encompassing over 20 million acres). This research currently emphasizes data gathering on natural resources and the processes that affect them.

The Bureau of Mines conducts mineral studies to provide information on mineral resources and the potential for mineral resource development. These activities include evaluation the mineral reserve potential of mineral-bearing areas, estimating the reserve base at specific deposits, and sampling ores, especially for critical and strategic minerals.

National Science Foundation

National Science Foundation research is concerned with the entire arctic region, including Alaska, Canada, Greenland, Svalbard, the Arctic Ocean and adjacent seas and the upper atmosphere and near space. Research falls principally within seven major scientific disciplines: atmospheric sciences, ocean sciences, biological sciences, earth sciences, glaciology, engineering and education.

Arctic atmospheric sciences research involves studies of arctic stratus clouds, arctic haze, long-range transport of aerosols and trace gases over the Arctic Basin, precipitation and dry deposition on glaciers and ice sheets, magnetosphere-ionosphere interactions, very low frequency waves, auroras, and precipitation of energetic particles from the magnetosphere.

Ocean Sciences research has concentrated on studies of how the high-latitude ocean system affects the climate of the world. Other research has concerned the biological communities in these northern waters.

Recent major activity in biological sciences research has concentrated on two long-term Ecological Research Projects in Alaska, one in the taiga (evergreen shrub forest) and the other in the tundra. Building on a decade of intensive ecosystem research, these studies deal with both primary successional processes in the floodplain of the Tanana River and the secondary succession in the uplands.

Earth sciences research is currently focusing on climatic change, as determined from marine, periglacial and soils geologic studies. Other projects are examining the depositional, vegetational and climatic history of sections of Alaska.

Glaciological research involves studying the physics of glacier flow, mathematical modeling of glaciers, ice streams and the Greenland ice sheet, and the chemistry of ice cores as indicators of long-term environmental change.

Engineering research involves studies of the mechanical properties of ice, the hydraulic conductivity of frozen soils, metamorphism of dry snowpacks, and three-dimensional analyses of ice and permafrost.

Education expenditures are currently being used to improve teaching of science, mathematics and engineering for Native Americans and in general supporting science and mathematics teaching in Alaska.

Department of Commerce

All the arctic research conducted by the Department of Commerce is done by the National Oceanic and Atmospheric Administration. NOAA performs arctic research within its environmental monitoring and prediction responsibilities. Several individual research programs focus on scientific questions addressing the arctic environment and its relationship to the global environment. NOAA also conducts research in support of the services it performs, such as weather forecasting and fisheries management. Recent activities of NOAA have been prediction of sea ice cover in the Arctic, surveys of fisheries resources, and of course, weather and hydrological prediction.

NASA

The National Aeronautics and Space Administration supports several programs in the Arctic that emphasize the application of air- and space-borne research to studies in the earth and space sciences. These programs include the investigation of oceans and their ice sheets, atmospheric chemistry, space plasma physics and land processes.

The largest category of NASA research is under the Polar Oceans and Ice Sheets Program, which focuses on the use of space-borne sensors to determine the characteristic of the arctic ice cover and its effects on the overlying atmosphere and underlying ocean. The program concentrates on remote sensing techniques that operate in the microwave portion of the electromagnetic spectrum, since these methods are not constrained by either darkness or clouds, which commonly limit observation in the Arctic. Other research is investigating the aurora phenomenon, which can have a severe impact on communications, and the dynamics of the upper atmosphere, including the arctic ozone layer and the troposphere.

Department of Energy

Recent DOE arctic research efforts have included studies of the effects of landscape disturbance, carbon dioxide enrichment of the atmosphere, seismology, auroral disturbances in the magnetosphere, energy data base management and unconventional methods of recovering natural gas. Landscape disturbance studies have concentrated on mapping Alaskan tussock tundra ecosystems, including snow distribution, wind direction, solar input, soil type and biomass. The CO_2 studies have concentrated on tundra response to carbon dioxide enrichment and the recovery studies have concentrated on retrieval of gas hydrates.

Department of Health and Human Services

As would be expected, DHHS research concentrates on the health of people living in the Arctic. This research is conducted primarily by the Centers for Disease Control and the National Institutes of Health. Collaborative studies are also performed with health care providers such as the Indian Health Service, the Alaska Department of Health and Human Services and the University of Alaska. Current projects are trying to eradicate hepatitis B infections among Alaskan Natives, and to decrease the incidence of streptococcal pneumonia, which has an incidence as much as fifty times greater among the Alaskan Native population than among the overall U.S. population.

Smithsonian Institution

The Smithsonian conducts activities, primarily in arctic anthropology and biology, throughout the entire area of the North American Arctic. In 1988 the Smithsonian received new funding for an arctic studies program in anthropology, biology and museum studies. In addition, the Smithsonian has developed arctic education programs for Alaskan Natives and for tourists.

Department of Transportation

The Department of Transportation's arctic research is performed primarily by the Coast Guard and Federal Highway Administration. The U.S. Coast Guard conducts research relating to a variety of its traditional missions in the Arctic, including search and rescue, promotion of marine safety, enforcement of laws and treaties, environmental protection, and support of national defense and the missions of other agencies. In addition, extensive DOT research is being conducted on arctic roadways. Projects related to the Arctic and other cold regions have included studies of the bond structure between ice and pavements, evaluation of deicing chemicals, the development of snowplows and improved methods for controlling blowing snow, and understanding the mechanisms of frost action on concrete.

Department of Agriculture

The Department of Agriculture supports arctic research on forests, rangelands, soils and snow in Alaska. Current research efforts have concentrated on vegetation classification, the results of fires on the tundra and in forests, forest pathology and entomology, biological diversity and long-term site productivity.

CONCLUSIONS

The U.S. Government's Arctic Research Program invested nearly $100 million in fiscal year 1988 to find ways of improving the living and working conditions in the arctic regions. This commitment of research resources demonstrates the value that is now placed on this "last frontier" of the United States. As shown by the descriptions of the studies being done by each organization, this research is no longer restricted to resource development or environmental protection but spans the entire range of the research needs of more temperate climates. Furthermore, private corporations have also invested extensively in research pertaining to the U.S. Arctic, so that the total of both private and public research dollars is appreciably higher than the figure given above. This expenditure for arctic research has consistently shown an upward trend that will undoubtedly continue as northern Alaska becomes more developed and populated.